A Two-level Computable Equilibrium Model to Assess the Strategic Allocation of Emission Allowances Within the European Union*

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Abstract

This paper deals with the modeling of the strategic allocation of greenhouse gases emission allowances in the EU-wide trading market that results from Kyoto agreement implementation. An M-matrix game is formulated where the players are countries or groups of countries that may have a strategic influence through their allocation of emission allowances and the payoffs are the welfare gains of these countries, evaluated from a multi-country computable general equilibrium model. To solve the matrix game one uses the concept of correlated equilibrium which makes sense in the context of EU negotiations. One studies several formulations of that two-level game structure and, in all these instances, we obtain a unique equilibrium solution that can be given an interesting interpretation for establishing a scheme for greenhouse gas emission allowance trading within the Community.

1 Introduction

The aim of this paper is to propose a two-level game model to assess the strategic allocation of greenhouse gas emission allowances in the EU-wide market that will be implemented, following the Kyoto agreement. It is well established that a market for emission allowances is an efficient way to implement the abatements decided in the Kyoto agreement [19] [30] [34]. Economic theory tells us that the way the emission allowances are initially allocated among the different agents in the economy does not matter, in terms of global welfare

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effect: Pareto efficiency is achieved irrespective of the initial allocation [17]. However there are market imperfections in the European economies that can challenge the efficiency of trading. In [5], it is shown that some countries can be worse off with trading than without because of imperfections due to pre-existing tax distortions. Another source of imperfection comes from the limitation of the emission permits market to some sectors of the economy. These market imperfections may create a situation where some dominant countries strategize their allocation of allowances.

Since European economies are closely linked, and also open to the rest of the world, the consequences of these strategic choices must be evaluated through the use of a world-wide multi-country computable general equilibrium (CGE) model that provides an evaluation of welfare gains of the different countries when the emission trading market is implemented. We shall therefore identify an ensemble of M-matrix games, where M represents different possible sets of strategic players and where the payoff matrices are obtained from the solution of all the general economic equilibrium problems associated with the different possible M-strategy choices. Once the M-matrix game is identified we look for the solutions called correlated equilibrium [2]. The set of correlated equilibria is obtained through the solution of linear programs. In our numerical experiments it turns out that this set of equilibria always reduces to a singleton which then corresponds to a unique Nash equilibrium in pure (instead of mixed) strategies.

Multi-market equilibrium models have been used to estimate payoff matrices for a game-theoretic analysis of the incentives of OECD regions to comply with a non-binding agreement in a carbon abatement coalition [3]. In [16], it is shown that Nash equilibria can be directly computed within a general equilibrium framework. In the present paper, we propose to use a two-level approach which is simpler, although computer intensive, to implement. The fact that we obtain single correlated equilibria in pure strategies simplifies the interpretation of these solutions.

The rest of the paper is organized as follows: in section 2 we describe the issue of strategic allocation of emission allowances in the EU-wide emission trading market; in section 3 we describe the two-level game structure and the correlated equilibrium solution concept; in section 4 we briefly indicate how the multi-country general equilibrium model is set up; in section 5 we define the different matrix games that will be solved for their correlated equilibrium solutions; in section 6 we discuss the results obtained for different possible games; in section 7 we conclude. In Appendix 1 we give the AMPL code for finding the correlated equilibrium solutions.

2 The issue of strategic allocation of allowances

In the process of pushing forward the implementation of emission trading at the EU level, the European Commission has published a directive for greenhouse gas emission allowance trading within the Community [22]. The directive states that only selected sectors will have the opportunity to participate in the CO_2 permit market in the first period (2005-2008). The market will probably be extended in the next periods to other GHG emissions, other sectors, and other countries (e.g. accession countries). According to the Commission, Member States will have to decide on the allocation across 1) the trading and non-trading sphere, and 2) across trading sectors. The emission allowances to be allocated to the trading sector will be given for free in the initial period. Finally, the Commission does not impose harmonization on permit allocation rules but asks for submission of national allocation plans.

Initial allocation of allowances is a complex process: (i) Based on the Kyoto agreement, the EU had to reallocate the global target across countries; (ii) Member States have to decide on the total amount of allowances that will be given to the trading sector; (iii) Then, emission allowances have to be distributed to individual industries included in the trading sector; (iv) Finally, emission allowances have to be allocated to individual installations. Figure 1 summarizes this process.

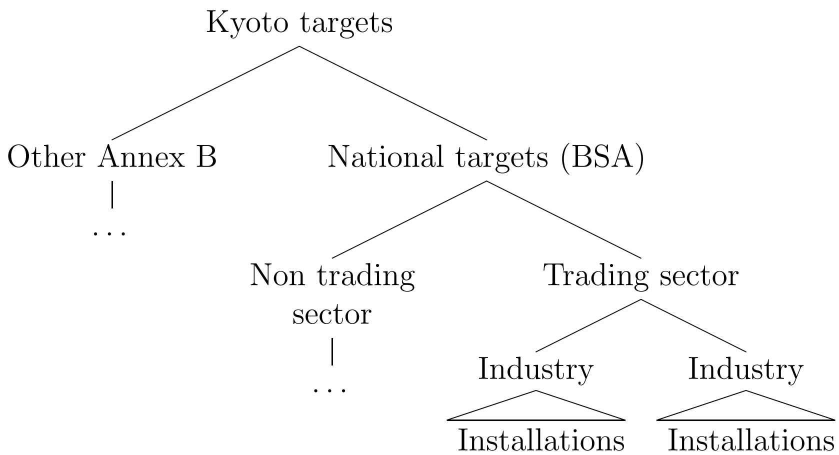

Figure 1: Allocation of Allowances Within the Community

As pointed by Böhringer and Lange [14] one might worry about the possibility that governments play strategically with the initial allocation of permits due to competitiveness concerns. Indeed, some EU countries might be tempted to "subsidize" opened sectors such as energy-intensive industries in order to protect them [4] [33]. For example, Member States could opt for an output-based permit allocation to alleviate the adverse adjustment effects on energy-intensive industries [27].

Since the beginning of the 1980s, much research has been devoted to the analysis of strategic trade policies, that is the incentive for governments to intervene in order to alter the strategic interaction between oligopolistic firms [15] [20]. Recent research along these lines has developed international oligopoly models that combine incentives for pollution control with the rent-shifting motivations for trade policy first noted by Brander and Spencer in [15]. The potential use of environmental regulations to achieve competitive advantage in international markets has also received a great deal of attention since the 1990's [6] [18] [29].

Hence, the question arises how some European countries could intervene and subsidize their energy-intensive industries through the allocation of tradable emission allowances. Intervention is generally helpful for the subsidized sector but intervention may be welfare decreasing for the economy as the whole (e.g. higher burden in non-subsidized sectors) [4]. Each country's strategy will be defined in response to the other countries strategy. This means that one should represent the problem as a non-cooperative game and look for some equilibrium solution. The institutional set-up where the countries may enter into preplay communication gives a justification for the use of the *correlated equilibrium* concept, further discussed in the next section.

3 Correlated equilibria in a two-level game

The games that we shall study are defined in the following way:

The players : Countries or groups of countries that may strategize the allocation of allowances;

The strategies : The different (contrasted) allocation schemes that can be chosen by these players;

The payoffs : The welfare gains (-losses) for each player resulting from the Kyoto emission targets under the EU-wide trading regime.

We say that these games have a two-level structure since the strategies selected by the players have consequences that are calculated from a computable general equilibrium model, as summarized in the figure 2 below.

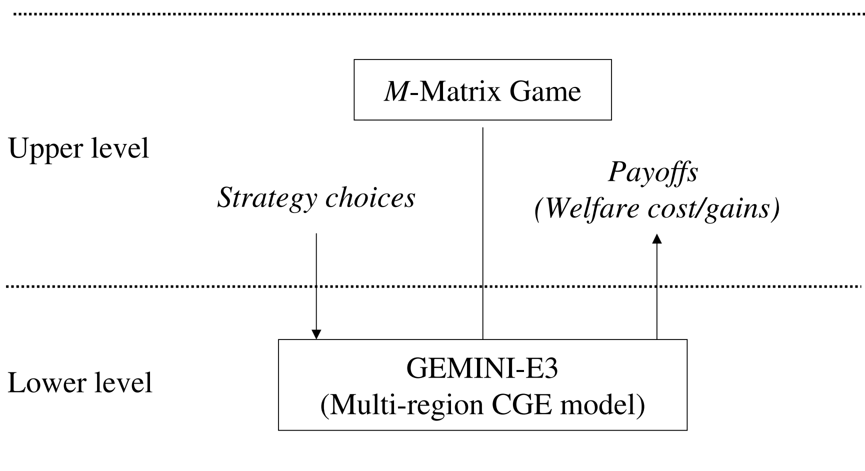

Figure 2: The two-level game structure

The upper-level game will therefore be represented as an M-matrix game, where M is the set of active countries and where the payoffs are obtained by running GEMINI-E3 under the configurations associated with the different possible strategy choices. The upper-level game will be solved for the characterization of the set of *correlated equilibria*. The concept of correlated equilibrium has been introduced by Aumann [2] as a convenient way to describe the set of equilibrium outcomes that could result from playing any *communication game* generated from a strategic-form game by adding a system of pre-play communication between the agents. We refer to the excellent textbooks [25] and [31] for a complete presentation of the concept. The game in strategic form is defined by $\Gamma = (M, (S_j)_{j\in M}, (u_j)_{j\in M})$ where M is the set of players, S_j is the set of our strategies of player j and $u_j : \Pi_{i\in M} S_i \to \mathbf{R}$ is the payoff function for player j. Let us denote $\mathcal{S} = \Pi_{i\in M} S_i$ and $\mathbf{s} = (s_j)_{j\in M} \in \mathcal{S}$. A correlated equilibrium is defined by a probability distribution on $\mathcal{S}$, $\pi(\mathbf{s}) \geq 0$, $\sum_{\mathbf{s}\in\mathcal{S}} \pi(\mathbf{s}) = 1$ such that the following inequalities hold

$$\sum_{\mathbf{s}\in\mathcal{S}} \pi(\mathbf{s}) u_j(\mathbf{s}) \geq \sum_{\mathbf{s}\in\mathbf{S}} \pi(\mathbf{s}) u_j(\mathbf{s}_{-j}, \sigma_j), \quad \forall\, j \in M, \forall\, \sigma_j \in S_j. \tag{1}$$

$$\text{where } (\mathbf{s}_{-j}, \sigma_j) = (s_i, ..., s_{j-1}, \sigma_j, s_{j+1}, ..., s_m).$$

and M = 1,...,m.

The interpretation can be the following: through a preplay communication scheme the agents may exchange signals that sum up to each player receiving a recommendation to play a given strategy. The probability $\pi(\mathbf{s})$ is affected to the event: *the vector* $\mathbf{s}$ *is recommended as a way to play the game*. We have to realize that, in this interpretation, each player knows only the recommendation to play that concerns him. The inequalities (1) express the fact that a player has no incentive to play other than as recommanded.

In brief we could view a correlated equilibrium either as the result of playing a game where a *mediator* sends private information to each player, in the form of a recommendation to play a given strategy, or as the result of the use of communication strategies by the players, where each player would send reports to the other players (and receive reports from the others) before deciding what to do. We can see the relevance of this scheme in the context of EU-wide negotiation for the implementation of a tradable emission permit scheme.

It is well known that the set of correlated equilibria in an M-matrix game is closed and compact and can be characterized through the solution of linear programs. The set of correlated equilibria contains the set of Nash equilibria. Therefore, if this set of correlated equilibria reduces to a singleton, it is the unique Nash equilibria for the game.

4 Lower level economic equilibrium model

GEMINI-E3 is a multi-country, multi-sector, dynamic-recursive CGE Model that incorporates a highly detailed representation of indirect taxation. This version of GEMINI-E3 is formulated as a Mixed Complementarity Problem (MCP) using GAMS with the PATH solver [23][24]. The third version of GEMINI-E3 has been especially designed to calculate the social marginal abatement costs (MAC, i.e. the welfare loss of a unit increase in pollution abatement), and to simulate tradable emission permits markets based either on market prices (carbon tax) or on social marginal costs. A full description of the model is provided in [9] and [13].

The model has been used to analyze the implementation of economic instruments for GHG emissions in a second-best setting [10], to assess the economic impact of the US withdrawal from the Kyoto Protocol [11], and to analyze the behavior of Russia in the Kyoto Protocol [7][8]. Table 1 gives an overall description and the main characteristics of the model. Besides a comprehensive description of indirect taxation, the model simulates all relevant markets: e.g. commodities (through relative prices), labor (through wages), and domestic and international savings (through rates of interest and exchange rates). Terms of trade (i.e. transfers of real income between countries resulting from variations of relative prices of imports and exports), and then "real" exchange rates can be accurately modeled.

The new version of GEMINI-E3 used in this paper is built on a comprehensive energy-economy data set, the GTAP-5 database [26], that expresses a consistent representation of energy markets in physical units as well as a detailed Social Accounting Matrix (SAM) for a large set of countries or regions and bilateral trade flows.

Table 1: Dimensions of the GEMINI-E3 Model

Countries or Regions		Sectors
Annex B		***Energy***
Germany	DEU	01 Coal
France	FRA	02 Crude Oil
United Kingdom	GBR	03 Natural Gas
Italy	ITA	04 Refined Petroleum
Spain	ESP	05 Electricity
Netherlands	NLD	***Non-Energy***
Belgium	BEL	06 Agriculture
Rest of EU-15	OEU	07 Mineral products
Switzerland	CHE	08 Chemical Rubber Plastic
United States	USA	09 Metal and metal products
Japan	JAP	10 Paper Products Publishing
Eastern Europe[a]	CEA	11 Transport n.e.c. (road and railway)
Canada, Australia, and New Zealand	CAZ	12 Sea Transport
Former Soviet Union	FSU	13 Air Transport
Non-Annex B		14 Other Goods and services
China	CHI	
Brazil	BRA	***Household Sector***
India	IND	
Middle East and Turkey	MID	***Primary Factors***
Asia	ASI	Labor
Latin America and Mexico	LAT	Capital
Rest of World[b]	ROW	Energy
		Fixed Factor (for sectors 01-03)
		Other inputs

[a] Includes Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia.
[b] All countries not included elsewhere (mostly Africa).

Table 2: GEMINI-E3 Default Parameters

Parameter	Sector	Value	Parameter	Sector	Value
σ	All	0.30	σ_t	All	0.60
σ_{pf}	All	0.20	σ_m	All	0.20
σ_{pp}	All	0.10	σ_x	01	2.00
σ_e	All	0.40		02	10.00
σ_{ef}				03	2.00
	01 to 04	0.10		4, and 06 to 10	3.00
	03	0.10		05	0.50
	04	0.10		11 to 13	0.10
	05	1.50		14	1.50
	06 to 08, 10, and 14	0.30	σ_{ai}	2	10
	09, and 11 to 13			1, 3-14	2
σ_{mm}	All	0.20			

Figure 1 represents the structure of the production sector in the model. Production technologies are described using nested CES functions. The default values for elasticity parameters are reported in Table 2.

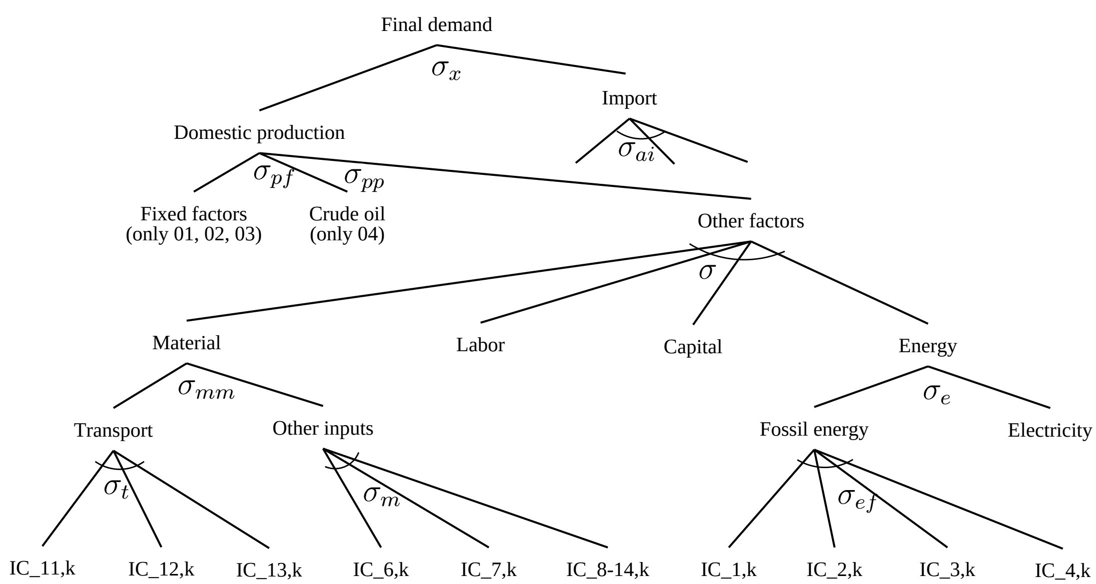

Figure 3: Structure of the Production Sector in GEMINI-E3

The household demand function is described by a linear Expenditure System (LES) derived from the Stone-Geary direct utility function [32]. The model employs a convention that is widely used in modeling international trade: the Armington assumption [1]. Under this convention a domestically produced good is treated as a different commodity from an imported good produced by the same industry. Indirect taxation and social contribution rates are differentiated by commodity (taxes on production, on imports), by sector (social contributions, subsidies), by sector $\times$ commodity (intermediate consumption), by commodity × institutional sector (final demand), and by commodity × sector × IS (investment, savings).

Time periods are linked in the model through endogenous real rates of interest determined by the equilibrium between savings and investment. National and regional models are linked by endogenous real exchange rates resulting from constraints on foreign trade deficits or surpluses.

The main outputs from the GEMINI-E3 model, by country, annually are: carbon taxes, marginal abatement cost and price of tradable permits (when relevant), net sales of tradable permits (when relevant), total net welfare loss and components (net loss from terms of trade, pure deadweight loss of taxation, net purchases of tradable permits when relevant), macroeconomic aggregates (e.g. production, imports and final demand), real exchange rates and real interest rates, and industry data (e.g. change in production and factors of production).

5 Upper level Allocation Game

In this paper, we represent a M-matrix game, where the strategic players are: Germany (DEU), the United Kingdom (UK), Italy (ITA), and the rest of the European Union (REU)[1]. These regions have to choose among four different rules to allocate emission allowances across economic sectors. As stated by the European Commission, there are three basic approaches, based on (i) historical emissions, (ii) forecast emissions, and (iii) economic efficiency ("least cost" approaches) [21]. We have retained two "historical emissions" approaches and two "least cost" approaches:

- *Grandfathering (GF)*:

  Emission allowances are allocated among sectors according to their historical emissions taking into account a global target of emissions reduction at the national level:

  $$Q_i^{2010} = E_i^{2001} \times (1 - \texttt{obj}) \tag{2}$$

  where Q_i^{2010} are the emission allowances of sector i in 2010, E_i^{2001} represents the emissions of i in the reference year (2001), and `obj` corresponds to a reduction target (25%) applied to eligible sectors in all European countries [2].

- *Historical emissions (HE)*:

  Under this approach the total number of allowances allocated to a given trading sector is determined by its share in each Member States emissions from economic sectors included in the trading scheme emitted in a particular year (e.g. 2001), multiplied by total allowable emissions for the economy; this rule is defined as follows:

  $$Q_i^{2010} = \frac{E_i^{2001}}{\sum_i E_i^{2001}} E_{\texttt{kyoto}}^{2010} \tag{3}$$

[1] We take Germany, the UK, and Italy as players because they account for around 30%, 17% and 14% of total EU emissions quotas respectively whereas France, for example, is only 6%.

[2] The -25% emission target has been defined so that the emissions allowances of the trading sectors are comparable to what is obtained with the other rules (see figure 4).

where $E^{2010}_{\mathtt{kyoto}}$ represents emission targets as defined in the Kyoto Protocol.

- *Domestic Tax-based (DT)*: According to this allocation rule, sectoral allowances correspond to the ones that would occur if a uniform carbon tax were to be implemented at the domestic level; allowances allocated to the trading sectors are defined as follows:

$$Q_i^{2010} = E_i^{\mathtt{DT}} \tag{4}$$

  where $E_i^{\mathtt{DT}}$ stands for the emission allowances for sector i under a uniform national tax that would meet the Kyoto targets.

- *European Tax-based (ET)*:

  According to this allocation rule, sectoral allowances correspond to the ones that would occur if a uniform carbon tax were to be implemented at the European level; allowances allocated to the trading sectors are defined as follows:

$$Q_i^{2010} = E_i^{\mathtt{ET}} \tag{5}$$

  where $E_i^{\mathtt{ET}}$ stands for the emission allowances for sector i under a uniform tax implemented at the European level to reach the aggregated Kyoto emission target.

As explained before, the payoffs are computed with the CGE model. Alternative measures of the economic impact of climate policies have been used in the literature: GDP, change in consumer surplus, discounted present value of consumption, and direct cost [28]. For micro-economists, and in particular welfare economists, the relevant measure is surplus, as it was originally defined by Dupuit, and is expressed in the modern welfare literature by the Compensating Variation of Income (CVI) [12]. In GEMINI-E3, welfare costs of climate policies are measured by the CVI through the indirect utility function. Welfare costs are decomposed into two components: (i) the deadweight loss of taxation, i.e. the domestic component of the welfare cost, and (ii) the terms-of-trade effect that corresponds to the change in the prices – or the quantities – of foreign trade. The model also represents the welfare effects of international emission trading. In the simulations, it is assumed that emission markets are perfectly competitive.

Three Games are simulated:

- **Game 1**: the 4 players can choose to allocate emissions allowances according to the domestic tax-based approach (DT), or deviate from this rule by giving 10 percent more (DT+10) or 10 percent less (DT-10) to the trading sector.

- **Game 2**: the 4 players can choose to allocate emission allowances according to the domestic tax-based approach (DT), the grandfathering approach (GF) or the European tax-based approach (ET).

- **Game 3**: the 4 players can choose to allocate emission allowances according to the domestic tax-based approach (DT), the grandfathering approach (GF) or the historical approach (HE).

In Game 1, one assumes that the reference rule for quotas allocation corresponds to the one equalizing marginal abatement costs across sectors at the domestic level (DT). In a first-best world, there is no incentive for governments to depart from this allocation rule since welfare are maximized. However, in a second-best world characterized by pre-existing tax distortions, welfare costs of climate policy might be reduced by reallocating some quotas toward the highly distorted sector[4]. In Game 1, we assess the incentive for EU countries to deviate from the DT allocation by giving 10 percent more (or less) quotas to the trading sector. In Game 2, the players can choose among more contrasted strategies. We allow EU countries to deviate a little bit more from the DT approach by giving even more (GF) or less (e.g. ET in Germany) quotas to the trading sector. In Game 3, the only way for EU countries to strategize on the allocation of quotas is to give more quotas to the trading sector; the GF approach corresponds to a lower deviation from the ET rule than the HE approach.

In order to get the payoffs for an M-matrix game with 4 players and 3 strategies, one has to run the GEMINI-E3 model 81 times (3^4). This process is computer-intensive since each run takes 30 minutes with a PC (Pentium 4 CPU 2.4 GHz and 504 Mo of RAM), namely 40.5 hours for each game. The computation of correlated equilibria, once the M-matrix game is identified, is very fast. The linear programming formulation is provided in AMPL format in Appendix 1.

6 Results

Figure 4 aims at comparing the emission allowances allocated to the trading sectors under different allocation rules. As shown in this figure, the “eligible” sectors would get more allowances in all regions with the historical approach than with the other rules. The ranking of the other rules is different from one region to another. For Germany, emissions-based approaches (GF and HE) tend to give more emission allowances to the trading sectors than the other rules (DT and ET). The European tax-based approach (ET) is the more restrictive for the trading sectors in Germany and the United Kingdom but not in Italy and the other EU countries.

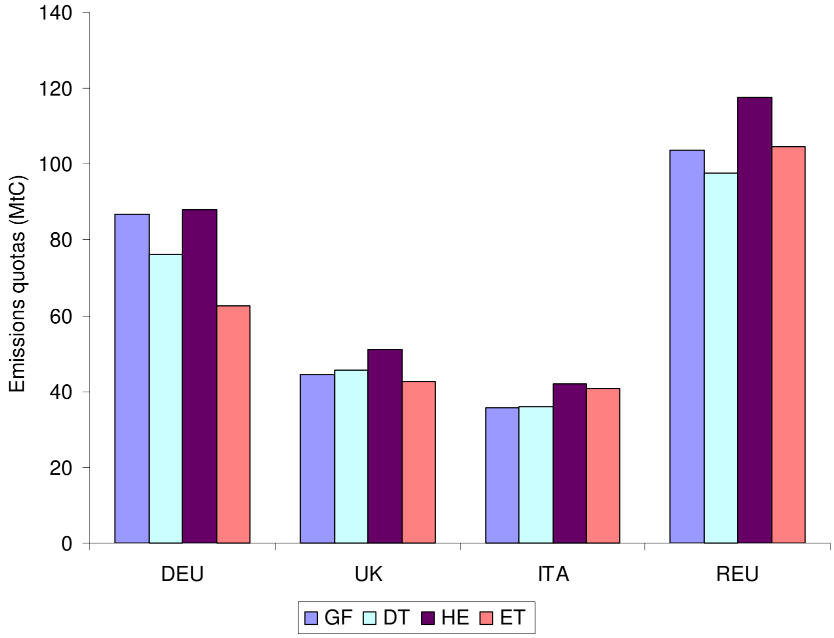

Figure 4: Emission Allowances by Region Under Different Allocation Rules

Table 3 shows that the games have a unique correlated equilibrium, and that the equilibria are always different from the competitive equilibrium solutions, where the different regions would play the same DT strategy. Germany, which is the main supplier of emission allowances, tends to rely on the domestic tax-based approach (DT) but the other regions, which are permits buyers, have an incentive to depart from this approach to maximize their own payoffs. In Game 1, Germany plays the domestic tax-based strategy (DT) whereas the United Kingdom decides to give less permits to the trading sectors (DT-10), and Italy and the other EU countries are more generous with their eligible sectors (DT+10). In Game 2, Germany and Italy allocate allowances according to the domestic tax-based approach (DT) whereas the United Kingdom and the rest of Europe opt for the grandfathering approach (GF). In Game 3, Germany opts again for the domestic tax-based approach (DT), the United Kingdom and the other EU countries choose the grandfathering approach (GF), and Italy uses the historical approach (HE).

In table 4, it is shown that the cooperative equilibria, obtained when the players maximize their joint utility, are different from the correlated equilibria. The table also shows

Table 3: Unique Correlated Equilibria

	Game 1	Game 2	Game 3
Germany	DT	DT	DT
United Kingdom	DT-10	GF	GF
Italy	DT+10	DT	HE
Rest of EU-15	DT+10	GF	GF

Table 4: Cooperative Solutions

	Game 1	Game 2	Game 3
Germany	DT+10	DT	DT
United Kingdom	DT-10	GF	GF
Italy	DT+10	DT	HE
Rest of EU-15	DT	DT	DT

Table 5: Payoffs in Correlated Equilibria versus Cooperative Equilibria

	Cooperative Equilibria			Correlated Equilibria		
	Game 1	*Game 2*	*Game 3*	*Game 1*	*Game 2*	*Game 3*
Germany	1254	1308	953	599	808	526
United Kingdom	-1646	-1807	-1526	-1880	-2090	-1933
Italy	-2665	-2854	-2726	-2614	-2844	-2709
Rest of EU-15	-4384	-4578	-4482	-4072	-4117	-4095
Total	-7442	-7931	-7781	-7967	-8244	-8211

that the cooperative solutions of the games do not correspond to the uniform strategies (e.g. harmonized allocation policy). The domestic tax-based approach (DT) is used more oftenly when the countries participate in an agreed solution to allocate allowances. However, because of market imperfections, the global welfare might be improved by adjusting the sectoral allocation of emission allowances [4] [5]. Table 5 shows that the outcomes of the non-cooperative equilibria are globally lower than what the players would obtain by playing the cooperative solution. There is no strict dominance of the correlated equilibria by the cooperative solutions with equal weight. Germany and the United Kingdom are always worse off with the non-cooperative solution but Italy and the rest of Europe are better off. Italy and the other EU countries have thus an incentive to depart from the cooperative solution.

Figure 5 compares welfare costs by region associated with the correlated equilibria. It is shown that an emission permits system based on the domestic tax-based approach (Game 1) would be more efficient than other systems, where the EU countries can opt for emissions-based approaches (e.g. Game 2 and Game 3). Even if some countries might be tempted to depart from the domestic tax-based approach and give more or fewer permits to the trading sectors, the equilibrium obtained in Game 1 is better than the equilibria in Game 2 and 3. The gains from emission trading would be reduced in the selling countries (mainly Germany) but the costs would be reduced in the importing countries (UK, Italy, and REU). In other words, this solution might improve the political acceptability of the EU-wide carbon emission market by limiting the distributive impact of emission trading.

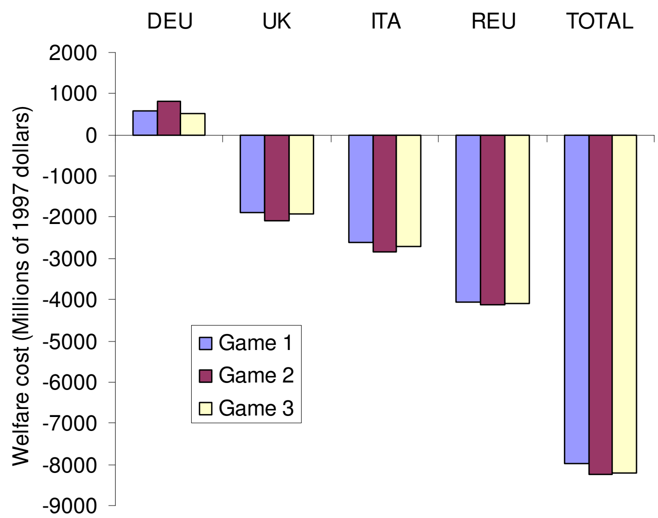

Figure 5: Welfare Costs in the Three Allocation Games

7 Conclusion

In this paper we have formulated an M-matrix game where the European countries have a strategic influence on the EU-wide emission trading regime through the initial allocation of emission allowances across economic sectors. A two-level game structure of the abstract game is implemented to investigate correlated equilibria.

The interpretation of the results is simplified by the uniqueness of the obtained correlated equilibrium. In particular this ensures that each player is playing according to the same equilibrium. Our results highlight the potentially important role of *communication* between countries (e.g. reporting and "action plan") and *mediation* (e.g. by the European Commission) in the process of initial allocation of emission allowances. The results suggest that the "mediator" should recommend that governments use the domestic tax-based approach to allocate allowances across sectors but that one should not except a full harmonization of allocation rules across the European Union. Indeed, some countries will have an incentive to correct the effect of market imperfections, e.g. the limitation of the trading system or the impact of pre-existing distortionary taxes, by adjusting the quantity of emission allowances allocated to the trading sectors.

Appendix 1. The AMPL code for solving a M-Matrix Game model

```
# Model for the allocation game between 4 European countries

set M:= {1,2,3,4}; # Players

param ns{M}; # Number of pure strategies for each player

param weight{M}; # Weighting of payoffs

set S {j in M} := {1..ns[j]}; # Pure strategy set Player j

set SS := S[1] cross S[2] cross S[3] cross S[4]; # Joint pure strategy set


# Gains

param G{M,SS} default 0; # Reward matrix for Players

# Permutations

param N{j in M}:=ns[j]^(ns[j]);

param delta{j in M, d in 1 .. N[j], S[j]} ;  # Permutations of Player j


# VARIABLES

var pi{SS} >= 0; # Joint probabilities

#Objective function

maximize totalvalue : sum{(s1,s2,s3,s4)in SS} pi[s1,s2,s3,s4]*
(weight[1]*G[1,s1,s2,s3,s4]+ weight[2]*G[2,s1,s2,s3,s4]+
weight[3]*G[3,s1,s2,s3,s4]+weight[4]*G[4,s1,s2,s3,s4]);


# Constraints


subject to norm : sum{(s1,s2,s3,s4) in SS} pi[s1,s2,s3,s4]=1;
# Normalizing probabilities
```

```
# Equilibrium conditions

equil1 { d in 1 .. N[1]}:
sum{(s1,s2,s3,s4) in SS} pi[s1,s2,s3,s4]*(G[1,s1,s2,s3,s4]-
G[1,delta[1,d,s1],s2,s3,s4])>=0;

equil2 { d in 1 .. N[2]}:
sum{(s1,s2,s3,s4) in SS} pi[s1,s2,s3,s4]*(G[2,s1,s2,s3,s4]-
G[2,s1,delta[2,d,s2],s3,s4])>=0;

equil3 { d in 1 .. N[3]}:
sum{(s1,s2,s3,s4) in SS} pi[s1,s2,s3,s4]*(G[3,s1,s2,s3,s4]-
G[3,s1,s2,delta[3,d,s3],s4])>=0;

equil4 { d in 1 .. N[4]}:
sum{(s1,s2,s3,s4) in SS} pi[s1,s2,s3,s4]*(G[4,s1,s2,s3,s4]-
G[4,s1,s2,s3,delta[4,d,s4]])>=0;
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