THE EUROPEAN ELECTRICITY MARKET – WHAT ARE THE EFFECTS OF MARKET POWER ON PRICES AND THE ENVIRONMENT?

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Paper presented at EcoMod2005 International Conference on Policy Modeling, June 29 – July 2, 2005, Istanbul, Turkey

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Date: 29 April 2005

Abstract

This paper presents a static computational game theoretic COMPETES model. This model is used to study the economic and environmental effects of the liberalisation of the European electricity market. The COMPETES model takes strategic interaction into account. The model is calibrated to four European countries: Belgium, France, Germany and the Netherlands. To analyse the impact of emission trading, a fixed permit price per tonne CO_2 emissions is introduced. The effects are studied under different market structures depending on the ability of firms to exercise market power. The results indicate that the effects of liberalisation depend on the resulting market structure, while a reduction in market power of large producers may be beneficial for the consumer (i.e. lower prices), this is not necessarily true for the environment (i.e. lower reduction in CO_2 emissions).

Keywords: Electricity market; liberalisation; market power; game theory; environmental impacts; Northwestern Europe.

JEL–classification: C7, D2, Q4, R3

1. INTRODUCTION

By the year 2007 all EU-15 member countries will have liberalised their electricity markets if they live up to their commitments according to EU Directive 96/92/EC. The European electricity market is currently in the midst of a drastic transformation from monopolistic, national and state-owned producers to a market with competing, private and often multinational firms. Although the speed and current state of this process vary widely across Europe, this process will definitely affect the structure of the European electricity market. In the present European electricity market we can see a whole range of different structures from a near-monopoly in France to highly competitive markets in the Nordic countries.

Yet little is known about the environmental consequences of liberalisation. The main goal of liberalising the electricity market is to achieve more cost efficient production and lower electricity prices. On the one hand, this may be beneficial for the environment since more cost efficient production may reduce the burden on the environment, while, on the other hand, lower market prices imply higher electricity demand that increase the burden on the environment. Moreover, in the near future, new developments, such as the implementation of the EU CO_2 Emission Trading System (ETS) in 2005, may have major environmental impacts (Sijm 2004).

To study this complex process, we develop a static computational game theoretic model, which can study economic and environmental consequences of different market structures. The model allows us to answer questions about the wholesale price and demand for electricity, profits of electricity producers, and emissions to the environment. The model covers four Northwestern European countries, namely Belgium, France, Germany, and the Netherlands, which we for simplicity refer to as "EU4".

The model captures different market structures depending on firm's abilities to exercise market power. The two extreme cases are, on the one hand, perfect (or price) competition where firms do not exercise market power (also referred to as Bertrand equilibrium) and, on the other hand, strategic (or quantity) competition where firms fully exercise market power (also referred to as Cournot equilibrium). In between these two extreme market structures there are several possible oligopolistic market structures where firms exercise market power to a more limited extent.[1]

To study a policy that aims at reducing market power, we also consider a scenario where EdF in France cannot exercise market power in the French market. This is a useful scenario, as the French market is still regulated which avoids EdF from fully exercising market power. The actual production decision of EdF will be somewhere in between these two extreme scenarios.

To study possible environmental consequences of liberalisation, we consider scenarios with a CO_2 permit price of 0, 10 and 20 €/tonne CO_2. The CO_2 permit price of zero is likely to vary between 0 and 20, with 10 a likely average in the first commitment period (2005-2007). Hence, the results of this paper provide insight into the possible outcomes of the introduction of the EU-ETS, which started in January 2005.

The COMPETES (COmpetition & Market Power in Electric Transmission and Energy Simulator) model version 1.4, which is presented in this paper, is a simplified version of the original model in Hobbs et al 2004a,b. The original model also allowed for congestion on six nodes in the Netherlands and two nodes in Belgium. This congestion is generally not observed in the national networks and it is possible to simplify the model to considering one node per

[1] For instance, this is true for models with supply function equilibrium, where the firms do not fully exercise market power. Solving such models is computationally more demanding.

country. A similar analysis as done in this paper has been undertaken by Lise et al (2005), however, the calibration that model is based on more aggregate data.

Bower et al (2001) have simulated the liberalised German electricity market using an agent-based model. They conclude that mergers increase market power leading to higher electricity prices. Their model is very sensitive to the out-phasing of expensive oil-fired plants, nuclear energy, and to closing the borders to imports of (cheap) electricity. In all these instances, prices jump up considerably. Bigano and Proost (2002) conducted a four-country study (France, Germany, Belgium, the Netherlands), which is linked through electricity trade. The environmental impacts are quantified and a 3-stage game is calculated in a partial equilibrium framework. They compare strategic action with perfect competition to conclude that phasing out nuclear energy leads to a substantial decrease in social welfare. Newberry (2001, 2002) discusses the potential difficulties in liberalising the EU electricity market. He argues that, due to insufficient regulation, the targeted lower price effect can be offset.

Several authors have examined different non-cooperative games within various markets. Murphy *et al* (1982) have demonstrated how mathematical programming approaches can be used to determine oligopolistic market equilibria. Salant and Shaffer (1999) have illustrated the theoretical impacts on production and social welfare via two-stage Cournot-Nash equilibrium solutions, where learning-by-doing and investments in R&D determine marginal costs of identical agents differently. For Europe, Jing-Yuan and Smeers (1999) have modelled an oligopolistic electricity market with a sophisticated game theoretic model. More generally, Helman *et al* (1999) have investigated different kind of trade options and strategic price setting within the electricity market. Stern (1998) and Boots *et al* (2004) have investigated the liberalisation of the European gas market.

The outline of this paper is as follows. The next section provides an elaborate introduction to the model. Section 3 presents some illustrative results to demonstrate the scope of the model. The final section concludes.

2. MODEL DESCRIPTION

The effect of an ETS and market power are investigated using the COMPETES model which is described mathematically below (see also Hobbs et al 2004a,b). COMPETES covers Northwestern Europe: the Netherlands, Belgium, Germany and France. It can calculate the optimal outcome under perfect Bertrand competition and imperfect strategic Cournot competition. Furthermore, the consumers in COMPETES are price sensitive (elasticity of -0.4 under perfect competition). Also, the model is static and only considers short run variable costs.

The level of detail in the COMPETES model is quite extensive. The model contains various characteristics of 4668 power plants (acquired from http://www.platts.com/, the database on World Energy Power Plants), among others the location, production technology, availability, and CO_2 emissions. Firms can own power plants in various countries and have in effect active cross-border ownership relations. The year is divided into 12 demand periods varying from lowest demand to a super peak (derived from data at http://www.ucte.org/). Consumer demand is met under perfect competition, which results into market clearing prices and by assuming a price elasticity of –0.4, completes the affine consumer demand curve. Trade among the four countries is delimited by inter-connector transmission capacity (derived from data at http://www.etso-net.org/). Net losses from production to consumption are assumed to be zero in the model.

2.1 MODEL NOTATION

Variables are designated as lower case Latin letters (primal variables) or lower case Greek letters (LaGrange or dual variables), while coefficients are given in upper case. Dual variables are not defined in this subsection, but are instead introduced within parentheses to the right of their constraints in the models of the next Section. Indices and their sets are represented by lower and upper case Latin letters, respectively.

This paper uses the model COMPETES version 1.4, which only deals with inter-country path-based transmission system, implicitly assuming that there is no congestion within the national distributions networks.

2.1.1 Indices and Sets

$c,c'\in C$	Set of countries.
$f,f'\in F$	Set of generation firms.
$h\in H(f,c)$	Set of generating units owned by *f* in country *c*.
$m\in M$	Set of constrained interfaces with net transfer capabilities.
$p\in P$	Set of periods {(w, super peak), (w, peak), (w, shoulder), (w, off peak), (s, super peak), (s, peak), (s, shoulder), (s, off peak), (m, super peak), (m, peak), (m, shoulder), (m, off peak)}

2.1.2 Primal Variables

If a variable *x* has an asterisk (x^*), this indicates that the variable is exogenous to the generation firms and TSO, but endogenous to the market. An example can be a price variable *p*; a price taking firm naïvely views it as fixed, even though the full market model equilibrates price to order to equate supply with demand.

Generator's physical variables

g_{fchp}	MW generation by unit *h* owned by firm *f* in country *c* in period *p*.
s_{fcp}, s_{fcp}^*	MW sales by firm *f* in country *c* in period *p*.
s_{-fcp}, s_{-fcp}^*	MW sales by firms other than *f* in country *c* in period *p*.
$t_{fcc'p}$	MW power sales by *f* in country *c'* assigned to generation in country *c* in period *p*.

Hence, a firm can make inter-temporal decisions and has the choice among three different variables: How much and when where to generate and with which technology? How much and when where to sell? How much and when to transport from one country to another?

Arbitrager's variables

ap_{cp}	Net MW purchased by arbitragers in country *c* and transferred to other countries in period *p*.
as_{cp}	Net MW sold by arbitragers in country *c* and transferred from other countries in period *p*.
$t^a_{c'cp}$	MW power sales by arbitrager in country *c'* assigned to arbitrager purchases in country *c* in period *p*.

TSO's variables

z_{mp}	MW of flow through constrained interface *m* in period *p*.

Price variables

p^*_{cp}	€/MWh in country *c* during period *p*.
wt^*_{mp}	€/MWh for transfer capability for interface *m* during period *p*.

2.1.3 Coefficients and Functions

Producer's coefficients/functions

$C_{fchp}(g_{fchp})$	Total cost, in € per period *p*, of production by firm *f* located in country *c* with technology *h* during period *p*.
Ξ_{fcp}	An index defining whether generator *f* behaves competitively (Ξ_{fcp}=0) or strategically (Ξ_{fcp}=1) in country *c* during period *p*.
G_{fch}	MW production capacity of generator firm *f* in country *c* with technology *h*.
MC_{fchp}	€/MWh marginal cost of generation for unit *h* owned by *f* at *c*, if an affine $C_{fchp}(g_{fchp})$ is assumed.

TSO's coefficients

PTC_{mp}	Net MW transfer capability for interface constraint *m* during period *p*.

Arbitrager's coefficients

$PTCU_{cc'mp}$	MW of transfer capability in interface *m* consumed by a 1 MW transfer from country *c* to country *c'* based on the administratively defined path from *c* to *c'*.

Market coefficients/functions

$EFEE_{cc'p}$	Fixed €/MWh export fee for sales from country *c* to country *c'*. This can also be used to model grid access charges if all exports from *c* (including "exports" to *c* itself) are charged the same fee.
$P_{cp}(\Sigma_f s_{fcp})$	€/MWh inverse demand function at *c* during period *p*. $P_{cp}(.)$ is defined as $P_{cp}(\Sigma_{f\in F} s_{fcp}) = A_{cp} + B_{cp}\ (\Sigma_{f\in F} s_{fcp})$, where A_{cp} is the price intercept of the demand function and B_{cp} is the slope. If this function passes through point $\{P^0_{cp}, S^0_{cp}\}$ and has an elasticity of $\varepsilon_{cp} < 0$ at that point, then $A_{cp} = (1–1/\varepsilon_{cp})P^0_{cp}$ and $B_{cp} = P^0_{cp}/(S^0_{cp}\varepsilon_{cp})$.

2.2 PROFIT MAXIMIZATION PROBLEMS AND MARKET CLEARING CONDITIONS

2.2.1 Generator's Model

Each generator *f* maximises profit by choosing generation g_{fchp}, sales s_{fcp}, trade $t_{fcc'p}$ and injection into pumped storage i_{fchp}:

$$\max_{\substack{q_{fchp}, s_{fcp} \\ t_{fcc'p}, i_{fchp}}} \sum_{c\in C}\left[\left(\left(1-\Xi_{fcp}\right)p^*_{cp}+\Xi_{fcp}P_{cp}\left(\sum_{f\in F}s_{fcp}\right)\right)s_{fcp}-\sum_{h\in H(f,c)}C_{fchp}\left(g_{fchp}\right)\right]$$
$$-\sum_{c'\in C}\left(EFEE_{cc'p}+\sum_{m\in M}wt^*_{mp}PTCU_{cc'mp}\right)t_{fcc'p} \qquad (1)$$

Subject to

$$s_{fcp}-\sum_{c'\in C}t_{fc'cp}=0 \qquad \left(\theta^S_{fcp}\right) \qquad (2)$$

$$-\sum_{h\in H(f,c)} g_{fchp} + \sum_{c'\in C} t_{fcc'p} = 0 \qquad \left(\theta_{fcp}^{G}\right) \tag{3}$$

$$g_{fchp} \le G_{fch} \qquad \left(\mu_{fchp}\right) \tag{4}$$

$$q_{fchp}, s_{fcp}, t_{fcc'p} \ge 0 \tag{5}$$

The generator can exercise market power on the sales to the consumer including usage for pumped storage. The market-power mark-up can vary from Ξ_{fcp}=0, i.e. Bertrand competition (perfect competition) and Ξ_{fcp}=1 is equal to Cournot competition (oligopoly strategic competition). The cost of transport is the sum of TSO services and a fixed export fee. There are losses only once the electricity is being distributed for consumption including consumption via pumped storage. The generation capacity during peak demand can be increased for pumped storage hydro units according to the amount stored during the base demand. The amount of addition pumped storage is also delimited.

2.2.2 TSO Model

The TSO efficiently allocates scarce transmission capacity to the most highly valued transmission services. By "efficiently", we mean that the value of services (as revealed by the market price of transmission, equalling the firms' marginal willingness to pay) net of transmission operating costs is maximised. Inter-country flows are subject to simple upper bounds, representing the assumed available transmission capacity.

$$\max_{z_{mp}} \sum_{p\in P} U_p \sum_{m\in M} wt_{mp}^{*} z_{mp} \tag{6}$$

subject to

$$z_{mp} \le PTC_{mp} \qquad \left(\psi_{mp}\right) \tag{7}$$

$$z_{mp} \ge 0 \tag{8}$$

Note also that it is not necessary to explicitly enforce mass balances at the nodes of the transmission network for the z_{mp}, as these will automatically be satisfied because of (3) and the market clearing constraints below.

2.2.3 Arbitrager

The arbitrager maximises profit based on price differences between nodes and transmission payments, subject to constraints that define between-country flow based on the amounts arbitraged:

$$\min_{t_{cc'p}^{a}} \sum_{p\in P} U_p \sum_{c\in C} \sum_{c'\in C} \left(EFEE_{cc'p} + \sum_{m\in M} wt_{mp}^{*} PTCU_{cc'mp} \right) t_{cc'p}^{a} \tag{9}$$

subject to

$$as_{cp} - \sum_{c'\in C} t_{cc'p}^{a} = 0 \qquad \left(\theta_{cp}^{aS}\right) \tag{10}$$

$$-ap_{cp} + \sum_{c'\in C} t_{c'cp}^{a} = 0 \qquad \left(\theta_{cp}^{aP}\right) \tag{11}$$

$$-as_{cp} + ap_{cp} = 0 \qquad \left(\rho_{cp}\right) \tag{12}$$

$$as_{cp}, ap_{cp}, t_{cc'p}^{a} \ge 0 \tag{13}$$

2.2.4 Market Clearing and Consistency Conditions

$$p^*_{cp} = P_{cp}\left(\sum_{f\in F} s_{fcp}\right) \tag{14}$$

$$z_{mp} = \sum_{c\in C}\sum_{c'\in C} PTCU_{cc'm}\left(t^a_{cc'p} + \sum_{f\in F} t_{fcc'p}\right) \quad \left(wt^*_{mp}\right) \tag{15}$$

The first market clearing condition (14) is simply the definition of the demand function. Condition (15) says that transmission services match the flows resulting from producers' actions.

2.3 MARKET EQUILIBRIUM AS A MIXED LINEAR COMPLEMENTARITY PROBLEM

The complementarity model for calculating the market equilibrium is constructed by combining the following set of conditions:

- the first-order (Karush-Kuhn-Tucker) conditions for the profit-maximisation model for each generator *f*;
- the first-order conditions for the TSO model;
- the first-order conditions for the arbitrager model;
- the market clearing conditions.

The result, if properly formulated, will be a "square" system in which the number of conditions (either equalities or complementarity conditions) will equal the number of variables. Note that the set of variables will also include dual variables for the constraints (2)–(4), (7), (10)–(12), in addition to the decision variables defined above. In general, it will be possible to use some or all of the equality constraints to eliminate some variables and thus simplify the model.

The complementarity model can then be solved numerically (using the PATH solver in AIMMS) to obtain a solution for a given set of parameters. The model can also be analysed for properties such as existence and uniqueness of solutions, and for relationships among the variables. The mixed complementarity problem below is a linear one if the indicated derivatives are affine. The problem is square (there are as many equations as variables).

Before coming to the KKT conditions it is helpful to formulate the generator, TSO, and arbitrager problem as a Lagrangian, namely as follows:

$$\begin{aligned}
L_f^{\text{Generator}} = \sum_{c\in C}\Bigg[& \left(\left(1-\Xi_{fcp}\right)p^*_{cp} + \Xi_{fcp}P_{cp}\left(\sum_{f\in F} s_{fcp}\right)\right)s_{fcp} - \sum_{h\in H(f,c)} C_{fchp}\left(g_{fchp}\right) \\
& - \sum_{c'\in C}\left(EFEE_{cc'p} + \sum_{m\in M} wt^*_{mp}PTCU_{cc'mp}\right)t_{fcc'p} \\
& - \theta^S_{fcp}\left(s_{fcp} - \sum_{c'\in C} t_{fc'cp}\right) \\
& - \theta^G_{fcp}\left(-\sum_{h\in H(f,c)} g_{fchp} + \sum_{c'\in C} t_{fcc'p}\right) \\
& - \mu_{fchp}\left(g_{fchp} - G_{fch}\right)\Bigg]
\end{aligned} \tag{16}$$

$$L^{\text{TSO}} = \sum_{p \in P} U_p \sum_{m \in M} wt^*_{mp} z_{mp} - \psi_{mp} \left(z_{mp} - PTC_{mp} \right) \tag{17}$$

$$\begin{aligned} L^{\text{Arbitrager}} &= \sum_{p \in P} U_p \sum_{c \in C} \left\{ \sum_{c' \in C} \left(-EFEE_{cc'p} - \sum_{m \in M} wt^*_{mp} PTCU_{cc'mp} \right) t^a_{cc'p} \right. \\ & \left. - \rho_{cp} \left(-as_{cp} + ap_{cp} \right) - \theta^{aS}_{cp} \left(as_{cp} - \sum_{c' \in C} t^a_{cc'p} \right) - \theta^{aP}_{cp} \left(-ap_{cp} + \sum_{c' \in C} t^a_{c'cp} \right) \right\} \end{aligned} \tag{18}$$

The KKT conditions can be derived from (14)–(18) by taking the derivatives with respect to the primal variables and the Lagrange multipliers as denoted by the lower case Greek letters.

The KKT conditions:

Generators:

$\forall g_{fchp}$: $$0 \le g_{fchp} \perp \left[\theta^G_{fcp} - MC_{fchp} - \mu_{fchp} \right] \le 0 \tag{19}$$

$\forall t_{fcc'p}$: $$0 \le t_{fcc'p} \perp \left[\theta^S_{fc'p} - \theta^G_{fcp} - EFEE_{cc'p} - \sum_{m \in M} wt^*_{mp} PTCU_{cc'mp} \right] \le 0 \tag{20}$$

$\forall s_{fcp}$: $$0 \le s_{fcp} \perp \left[p^*_{cp} + \Xi_{fcp} P_{cp}{}'(.) s_{fcp} - \theta^S_{fcp} \right] \le 0 \tag{21}$$

$\forall \theta^S_{fcp}$ $$\theta^S_{fcp} \perp \left[s_{fcp} - \sum_{c' \in C} t_{fc'cp} \right] = 0 \tag{22}$$

$\forall \theta^G_{fcp}$: $$\theta^G_{fcp} \perp \left[\sum_{c' \in C} t_{fcc'p} - \sum_{h \in H(f,c)} g_{fchp} \right] = 0 \tag{23}$$

$\forall \mu_{fchp}$: $$0 \le \mu_{fchp} \perp \left[g_{fchp} - G_{fch} \right] \le 0 \tag{24}$$

TSO:

$\forall wt^*_{mp}$: $$0 \le wt^*_{mp} \perp \left[z_{mp} - PTC_{mp} \right] \le 0 \tag{25}$$

Arbitrager:

$\forall as_{cp}$: $$0 \le as_{cp} \perp \left[\rho_{cp} - \theta^{aS}_{cp} \right] \le 0 \tag{26}$$

$\forall ap_{cp}$: $$0 \le ap_{cp} \perp \left[\theta^{aP}_{cp} - \rho_{cp} \right] \le 0 \tag{27}$$

$\forall t^a_{cc'p}$: $$0 \le t^a_{cc'p} \perp \left[\theta^{aS}_{cp} - \theta^{aP}_{cp} - EFEE_{cc'p} - \sum_{m \in M} wt^*_{mp} PTCU_{cc'mk} \right] \le 0 \tag{28}$$

$\forall \theta^{aS}_{cp}$: $$\theta^{aS}_{cp} \perp \left[as_{cp} - \sum_{c' \in C} t^a_{cc'p} \right] = 0 \tag{29}$$

$\forall \theta^{aP}_{cp}$: $$\theta^{aP}_{cp} \perp \left[\sum_{c' \in C} t^a_{c'cp} - ap_{cp} \right] = 0 \tag{30}$$

$\forall \rho_{cp}$: $$\rho_{cp} \perp \left[ap_{cp} - as_{cp} \right] = 0 \tag{31}$$

Market clearing:

$\forall p^*_{cp}$: $$p^*_{cp} = A_{cp} + B_{cp} \left(\sum_{f \in F} s_{fcp} \right) \tag{32}$$

$\forall z_{mp}$: $$z_{mp} = \sum_{c \in C} \sum_{c' \in C} PTCU_{cc'm} \left(t^a_{cc'p} + \sum_{f \in F} t_{fcc'p} \right) \tag{33}$$

3. RESULTS

In order to study possible environmental consequences of liberalisation, we add a CO_2 permit price to the model. While 10 €/tonne CO_2 is a reasonable estimate for the expected permit price, we also consider the case of 10€ lower and higher price. To study the influence of market power we consider consecutively three cases, namely perfect competition (COMP) and two Cournot competition scenarios: one where EdF cannot exercise market power in France (STRA) and one where EdF can (STRT). Table 3.1 summarises the resulting nine scenarios.

Table 3.1 *Definition of the nine scenarios.*

	CO_2 permit price (in €/tonne CO_2):		
Market structure:	0	10	20
Perfect Competition (PC)	COMP	COMP10	COMP20
Cournot competition (EdF PC in France)	STRA	STRA10	STRA20
Cournot competition by all large firms	STRT	STRT10	STRT20

The results of the nine scenarios as shown in Table 3.1 are derived by running the COMPETES model and can be presented in the form of national and EU4 (supply-weighted average) prices and EU4 total demand. Table 3.2 does this.

Table 3.2 *Weighted average national prices (in €/MWh) and total supply (in TWh) in nine scenarios.*

	COMP	COMP10	COMP20	STRA	STRA10	STRA20	STRT	STRT10	STRT20
Netherlands	42.93	47.18	51.07	57.38	62.20	65.92	57.42	62.23	66.01
Belgium	41.55	45.60	48.57	55.34	57.35	59.90	57.15	60.45	62.56
Germany	28.43	35.14	41.86	33.95	40.52	47.76	34.22	40.59	47.79
France	18.77	19.57	19.66	18.40	18.88	19.21	38.81	40.40	40.65
EU4 (price increase)	26.45	30.01 (+3.56)	32.78 (+2.77)	30.09	33.10 (+3.01)	35.82 (+2.72)	39.51	44.06 (+4.55)	48.15 (+4.09)
Total supply	1251	1175	1108	1180	1115	1049	967	892	827

Inspection of Table 3.2 yields that a higher CO_2 permit price leads to higher average prices, while total supply decreases (comparison over the cases in the rows of Table 3.1). This means that the introduction of a carbon price has an increasing effect on prices. The effect of market power is basically the same (comparison over the cases in the columns of Table 3.1), with a seeming exception in France (STRA*x*), but in these scenarios EdF behaves competitively and does not exercise market power. Once EdF does exercise market power (STRT*x*) prices go up considerably in all countries and even double in France.

Yet, there are considerable differences in the price increases due to the introduction of the carbon price. In the EU4 the price increase in the lowest in the scenarios with limited market power (STRA*x*), intermediate under perfect competition and the largest under full market power (STRT*x*). Furthermore, the price increase is higher for the first 10 €/tonne CO_2 than for the second (10+10) €/tonne CO_2, while this effect is most sharply observed in the case of perfect competition. This is a clear indication that the price increasing effect of a CO_2 permit price depends on market behaviour of the market participants, i.e. the ability of firms to exercise market power.

In addition to the price effects it is also possible to investigate the effects on emissions. The results are presented in Table 3.3 in the form of reference emissions in the COMP case and CO_2 emission reduction with respect to this reference case in percentages in the countries and EU4.

Table 3.3 *National and total CO_2 emission reduction in eight scenarios with respect to the amount of emissions in the COMP scenario (ktonnes CO_2).*

	COMP	COMP10	COMP20	STRA	STRA10	STRA20	STRT	STRT10	STRT20
Netherlands	59	–24%	–32%	–6%	–26%	–32%	–6%	–26%	–31%
Belgium	21	–9%	–11%	–49%	–60%	–67%	–14%	–48%	–59%
Germany	347	–17%	–34%	–14%	–30%	–47%	–11%	–30%	–47%
France	18	–34%	–37%	+8%	–30%	–39%	+32%	–49%	–58%
EU4	444.9	–18.6%	–33.0%	–13.8%	–31.1%	–45.5%	–8.6%	–30.8%	–45.7%

Table 3.3 shows that the introduction of a carbon price unanimously leads to a reduction in CO_2 emissions (comparison over the rows in Table 3.1). The effect of market power is more mixed over the countries. The most interesting result here is that the emissions in France somewhat increase under Cournot competition with zero permit price. Also, the overall reduction in emissions is higher in the case where EdF does not exercise market power (STRA) than in the case where EdF does (STRT). This effect evens out once the permit price goes up to 20 €/tonne CO_2. Hence, the effect of market power on emission reduction is mixed, but generally higher reductions are achieved in the case *with* market power.

4. CONCLUSIONS

This paper has presented the static COMPETES model. In addition, this model is used illustratively to study the effect of the recently introduced CO_2 emission trading system in Europe and the possibility of market power in the Norhtwestern European electricity market. Scenarios have been derived based on fixed permit prices per tonne CO_2 emissions and a variation in the ability of large producers to exercise market power.

The analysis of this paper indicates that the price increasing effect of a CO_2 permit price depends on market behaviour of the market participants. Furthermore, the effect of market power on emission reduction is mixed, but generally higher CO_2 emission reductions are achieved in the case *with* market power. Hence, in contrast to results found elsewhere (e.g. Lise et al 2005) a reduction in market power of large producers may be beneficial for the consumer (i.e. lower prices), but not for the environment (i.e. lower reduction in CO_2 emissions).

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