Intertemporal Emissions Trading and Market Power: Modeling a Dominant Firm with a Competitive Fringe

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Abstract In international emissions trading schemes such as the Kyoto Protocol and the European Union Emissions Trading Scheme, the suboptimal negotiation of the cap with respect to total pollution minimization leads us to critically examine the proposition that a generous allocation of grandfathered permits by the regulator based on recent emissions might pave the way for dominant positions. Stemming from this politically given market imperfection, this chapter develops a differential Stackelberg game with two types of non-cooperative agents: a large potentially dominant agent, and a competitive fringe the size of which are exogenously determined. Strategic interactions are modeled on an intra-industry permits market where agents can freely bank and borrow permits. This chapter contributes to the debate on the allocation of initial permits and market power by focusing on the effects of allowing banking and borrowing. A documented appraisal on whether or not such provisions should be included is frequently overlooked by the debate on whether or not to introduce the permits market itself among other environmental regulation tools. Numerical simulations provide a quantitative illustration of the results obtained.

Keywords Banking • borrowing • emissions trading • market power

JEL Codes C73, L11, Q52

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1 Introduction

What happens on a tradable permits market when distortions occur as a consequence of the initial allocation? Whereas Hahn (1984) first contributed to this debate by demonstrating the non-neutrality of allocating permits to an agent able to exert market power[1] in a static context and only concerning the spatial exchange of permits, this chapter addresses the critical aspect in the initial allocation of permits in a dynamic context and with respect to inter-temporal emissions trading. Theoretical analyses remain scarce in this domain, even if the properties of banking (i.e., the ability to stock permits for future use) and borrowing (i.e., the ability to borrow permits from future periods) have been detailed. In a continuous time model under certainty, Rubin (1996) shows that an intertemporal equilibrium exists on a permits market from the viewpoint of the regulator and the firm, and that banking and borrowing allow firms to smooth emissions. Under uncertainty, Schennach (2000) shows that the price of the permits may rise at a rate that is lower than the discount rate and new public information may cause jumps in the price and emissions paths, among other major contributions.

This chapter builds on the intertemporal emissions trading literature with market imperfections. It aims at filling the gap in the literature between the pros and cons of authorizing banking and borrowing in permit trading programs – a topic which is typically not debated enough when deciding whether to adopt such an environmental regulation system. Against this background, it attempts to shed some light on the ability of a large agent to move dynamic markets when permits are grandfathered.

Liski and Montero (2005b) study the effect of market power on the equilibrium of a permits market by introducing a large potentially dominant agent and a competitive fringe. Based upon two cases, their analysis firstly reveals that the large agent might manipulate the market by banking allowances when it owns the entire stock of permits and secondly that when the fringe receives the entire stock of permits, the large agent has an incentive to exchange permits at the competitive price and to build a permits bank for the next period. While previous papers restricted their analysis to banking only,[2] both banking and borrowing are allowed without restrictions in a continuous time setting.

The model enhances the regulatory economics literature with a realistic description of relationships between agents on a tradable permits market with information asymmetry. As Liski and Montero (2005b) did not impose a particular game structure, the Stackelberg game structure was adopted that enables one to deal with strategic interactions between two types of agents: a leader with an information advantage associated with a large agent, and a follower associated with a competitive fringe.

[1] For an exhaustive literature review on permits trading and market power, see Petrakis and Xepapadeas (2003).

[2] In fact, no major international agreement on greenhouse gases allowed borrowing to a full extent at that date.

The market imperfection arises from the free distribution of permits on the basis of past emissions, while the product market is assumed to remain competitive.[3] I explicitly include the Hotelling conditions[4] that must apply if permits are considered to be an exhaustible resource.

The chapter is structured as follows: firstly, the institutional framework of current permit trading programs is described, namely the Kyoto Protocol (KP) and the European Union Emissions Trading Scheme (EU ETS); secondly the Stackelberg game is developed and an expression derived for market power; thirdly numerical simulations for the price distortion condition are computed.

2 Institutional Framework

In this section, I describe how the model hinges on critical design issues of existing international emissions trading schemes, namely the KP and the EU ETS. I also attempt to provide a balanced picture of the EU ETS and KP market power concerns.

2.1 The Kyoto Protocol

The Kyoto Protocol came into force on February 2005 following the ratification of Iceland, and aims to reduce the emissions of six greenhouse gases (GHG) considered to be the main cause of climate change. Among the Members of Annex B, these agreements include the reduction of CO_2 emissions for 38 industrialized countries, with a global reduction of CO_2 emissions by 5.2%. One hundred and seventy-four countries, with Australia being the latest on December 3, 2007, have ratified the Protocol, with the notorious exception of the United States. The first commitment period of the Kyoto Protocol runs from January 1, 2008 to December 31, 2012.

The Kyoto Protocol is often referred to as “unfinished business.” Very heterogeneous sectors were included under the same regulation, which could be detrimental in finding the right method for allocating permits depending on price elasticities between sectors.

The intra-industry structure adopted in this chapter may be seen as a simplification of the KP. However it may propose useful policy recommendations when dealing with such an international scheme. In the following, the focus is on the negotiation phase, the special case of Russia and the prospective use of banking and borrowing.

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[3] For a distinction between the permits market and industry structure imperfections, see Sartzetakis (1997; 2004).

[4] Namely, the exhaustion and terminal conditions.

2.1.1 Negotiation Phase

Since no historical data is available on the cost of carbon emission reductions, it may prove particularly difficult to induce a cost-effective allocation of the initial quotas to participating countries. In the context of the KP, the case of countries supplied with allocations in excess of their actual needs has been coined as *Hot Air* in the literature.[5] The distribution of a large number of permits to the Former Soviet Union (FSU) and Eastern European countries (with Russia and the Ukraine accounting for two thirds) may indeed be seen as an imperfection of the KP, as those countries were given generous allocations to foster agreement during the first phase (2008–2012). Market power concerns arise as industrial companies may benefit from the gap between the allocation of their initial permits (based on 1990 production levels) and their real emission needs in 2008 (after a period of recession), and the use of these permit surpluses remains unclear. If a pure monopoly emerges, a single seller may price its output at a higher level than its marginal cost of production. Under international emissions trading, the case of relatively large buyers or cartels exerting market power sounds more relevant.[6]

This situation emerged as a conflict between the internal and the external consistency of the permits market:

- The *internal* consistency refers to the situation where agents freely receive or bid for permits according to their real needs. The regulator may be interested however in distributing more permits to a country than is strictly needed (according to business as usual emissions or a benchmark for instance) in order to ensure participation in the permits market.[7] As a consequence, one agent may achieve a dominant position, which in turn threatens the efficiency of the permits market itself.
- The *external* consistency of the permits market is linked to the broader debate of climate change as the purchase of a "global public good."[8] This altruistic view embodies the notions of "Burden Sharing" or "common but differentiated responsibilities"[9] attached to the KP, whereby developed countries agree to spend a higher share of their income on fighting climate change compared to developing countries.[10]

[5] See Baron (1999), Burniaux (1999), Bernard et al. (2003), Bohringer and Loschel (2003), Holtsmark (2003).

[6] One could symmetrically evoke the case of monopsony power whereby large buyers would lower the permit price from its level under perfect competition. Outlooks for the KP however do not match this perspective. Indeed, market power is more likely to come from sellers than from buyers.

[7] This kind of negotiation with Russia was a determining factor for the KP to come into force on February 16, 2005.

[8] See Guesnerie (2006).

[9] See Muller (2002).

[10] Note that the implicit assumptions of the existence of such an Environmental Kuznets Curve (the environment is a superior good and environmental regulation becomes stricter through time at higher levels of GDP per capita) has been left out of the debate.

These conflicting views undermine the negotiation of the cap, which is fixed at a suboptimal level compared to what would be needed to minimize the total damage to the environment. GHG emission targets under the KP represent a mere 5% reduction below 1990 levels. Now, if early movers such as the EU countries are willing to bring the cap down a gear, little progress can be achieved without the involvement of major players such as the USA, India and China. Thus, many difficulties arise in uncovering the "veil of uncertainty" that surrounds international negotiation.[11]

Uncertainty also affects the nature and the size of individual market participants. As Klepper and Peterson (2005) put it: "The Kyoto Protocol and its related decisions do not explicitly state who is actually supposed to be trading. Probably we will observe both government and firm trading. Under the former, market power might indeed become a relevant issue." Therefore, the risk of market power is higher if governments are trading large amounts of permits in a centralized manner.

The fact that the creation of a permits market gives some countries the opportunity to draw a financial advantage without any direct environmental gain (i.e., in the absence of effective emissions abatement) may be puzzling. Yet as stated by Maeda (2003), "[this debate] seems misguided because it focuses on the political importance of the issue, rather than addressing it from an economic perspective." For this reason I will investigate in this chapter how permit price manipulation strategies may incur additional economic costs to achieve the same level of abatement as under perfect competition.

Overall, the hypothesis that generous allocations that broaden the scope of a cap-and-trade program might also elicit dominant positions shall not be neglected. This leads me to comment on the case of Russia in more detail.

2.1.2 Will Russia Be a Net Seller of Permits?

Russia seems to provide the best example for investigating potential market power within the KP according to Korppoo et al. (2006): "Given the collapse of its emissions in the course of its economic transition, Russia is the country with by far the largest potential surplus of emission allowances for sale under the Kyoto international trading mechanisms. It is also generally considered to be the country with the greatest potential for continuing emission-reducing improvements in energy efficiency. Indeed, in the first commitment period under the Kyoto Protocol it could be described as the Saudi Arabia of the emerging carbon market, with the potential to try to manipulate the market through strategic decisions as to when and how it releases it surplus – if there are buyers willing to deal."

Empirical evidence gathered by Grubb (2004), Liski and Montero (2005a)[12] and Korppoo et al. (2006) suggested that Russia would be a net seller of allowances during the first phase of the KP. Different projections for Russian CO_2 emissions and surplus are provided in Tables 1 and 2.

[11] See Kolstad (2005).

[12] Based on the MIT-EPPA database that aggregates FSU countries.

Table 1 A survey of projections for Russian carbon dioxide emissions Adapted from Decaux and Ellerman 1998; Loschel and Zhang 2002; Korppoo et al. 2006)

Source	Year of estimate	Percentage of 1990 levels	Period
Decaux and Ellerman[a]	1998	73	2010
Russian energy strategy	2000	76–93	2012
Loschel and Zhang[b]	2002	83.6	2010
IEA[c] World Energy Outlook	2004	72	2008–2012
CEPA[d]	2004	75	2008–2012

[a]Scenario with Annex B Trading
[b]Scenario assuming trading without the United States
[c]International Energy Agency
[d]Cambridge Economic Policy Associates. Scenario with a 2% energy intensity reduction

Table 2 A survey of projections for Russia's surplus under the KP (Adapted from Decaux and Ellerman 1998; Loschel and Zhang 2002; Korppoo et al. 2006)

Source	Year of estimate	Size of the surplus[a]	Period
Decaux and Ellerman	1998	111[b]	2010
Loschel and Zhang[c]	2002	157.8	2010
Russian Ministry of Economic Development and Trade[d]	2003	408–545	2008–2012
Russian forecast to the UNFCCC[e]	2003	456–913	2008–2012
CEPA[f]	2004	400	2008–2012
Klepper and Peterson	2005	410	2010
Bohringer et al.	2006	246[g]	2008–2012

[a]In million tonnes of carbon equivalent (Mt Ce)
[b]Mt CO_2
[c]Scenario assuming trading without the United States
[d]Adapted from Korppoo et al. (2006)
[e]United Nations framework convention on climate change
[f]Cambridge Economic Policy Associates. Scenario with a 2% energy intensity reduction
[g]Mt CO_2

The key finding in Table 1 is that under all scenarios Russia would meet its Kyoto targets, as its CO_2 emissions projections consistently achieve levels well below its 1990 levels. The room for interpreting Table 2 is limited by the wide variation in surplus estimates with the lowest value of 111 Mt CO_2 found by Decaux and Ellerman (1998) and, as expressed above, by the current absence of clearly defined international trading rules to monetize such a surplus.

Further projections regarding Russia's own energy demand after the first period of the KP, are needed to determine whether or not Russian industrial companies might actually benefit from their *Hot Air*. Besides, the way in which *Hot Air* is dealt with also requires some consideration about a potential "leakage"[13] of emissions to

[13]As documented by Decaux and Ellerman (1998), the net effect of potential market power associated with Hot Air depends on the compensating emissions that might "leak" to regions unconstrained by the KP.

other regions that are not covered by the KP and additional allowances from the Clean Development Mechanism or Joint Implementation[14] that might compete with Russian allowances.[15]

2.1.3 Prospective Use of Banking and Borrowing in the KP

This section offers a description of the possible use of banking borrowing in the KP. On the one hand, provisions on banking are explained by Klepper and Peterson (2005): "Assigned Amount Units (AAUs) resulting from the Kyoto commitment can be banked without a time constraint. Credits from Joint Implementation (JI) or Clean Development Mechanism (CDM) can be banked up to a limit of, respectively, 2.5% and 5% of a Party's initial assigned amount. Sink credits cannot be banked."

On the other hand, implicit provisions on borrowing may be found in the United Nations Framework Convention on Climate Change (UNFCCC 2000) report.[16] As explained by Newell et al. (2005): "International climate policy discussions have implicitly included borrowing within possible consequences for noncompliance under the Kyoto Protocol, through the payback of excess tons with a penalty (i.e., interest)." This penalty could be fixed at 40% of additional emissions reduction for the next period of the Kyoto Protocol despite uncertainties regarding the enforcement of this particular provision. This question has been addressed in detail by Alberola and Chevallier (2009).

2.2 The European Union Emissions Trading Scheme

The European Union Emissions Trading Scheme (EU ETS) was launched on January 1, 2005 to reduce CO_2 emissions in the European Union by 8% by 2012, compared to 1990 emissions levels. The introduction of a tradable permits market was decided upon to help Member States achieve their targets for the Kyoto Protocol.

In the following, I comment on two critical aspects of the EU ETS. Firstly, I deal with possible design flaws in the allocation of permits that might pave the way for dominant positions during the first phase and secondly, I provide an overview of the prospective use of banking and borrowing.

[14]Conservative estimates range from a lower bound of 800 Mt CO_2 according to UKERC (2006) to an upper bound of 1,000 Mt CO_2 according to Point Carbon.

[15]As Baron (1999) put it, trading based on projects may reduce the risk of market power or shift it to other regions, which already host a large number of CDM projects such as China.

[16]UNFCCC (2000).

2.2.1 Over-Allocation or Relative Success?

The EU ETS imposes gentle constraints on emissions (8% reduction for EU-15) so as to start with a low carbon price. However the debate has now shifted towards a possible over-allocation of permits during the first phase. The production decisions of private actors are under scrutiny: do permit surpluses constitute a relative success (i.e., have companies reduced their emissions above projected levels?) or do they reflect an imperfection in the design of the system?

The CO_2 emissions reduction target of each Member State has been converted into a National Allocation Plans (NAP). Each government is in charge of deciding the amount of quotas available for trading, after negotiating with industrial companies, and after validation from the European Commission. The role of the Environment DG is central in this scheme in order to harmonize NAPs among Member States, and to recommend stricter validation criteria for NAPs. The NAPs that are submitted may be rejected by the European Commission, and sent back to Member States for revision before a final decision is granted. The sum of NAPs determines the number of quotas distributed to installations in the EU ETS.

Between 2005 and 2007, 2.2 billion allowances per year were distributed. Between 2008 and 2012, 2.08 billion allowances per year will be distributed, corresponding to a more restrictive allocation, given some changes in the scope of the market with the inclusion of new Member States.

Figure 1 represents the share of 2005 European Union Allowance Units (EUAs in million metric tons of CO_2 equivalent) among countries, where Germany, Poland, Italy, the UK and Spain stand out as the most important actors by accounting for about two thirds of the total allowances. Data is taken from CDC (2006)[17] and the *Community Independent Transaction Log* (CITL) administered by the European Commission.[18]

Figure 2 represents the share of quotas (in million metric tons of CO_2 equivalent) between Member States over the commitment period from 2008 to 2012. Germany, Poland, Italy, the UK and Spain make up for around two thirds of the allowances distributed.

While it is not our goal to comment on the structure of the European carbon market here, it is however interesting to look at the possible surplus with which those countries were endowed.

Figure 3 portrays the emissions reported for 2005 and, if any, the size of the surplus. The sum of the two bars is equivalent to the 2005 allocation of permits for a given country. Its main finding lies in the fact that most countries seemed to favor

[17] Tendances Carbone is published by the Caisse des Depots, and is available at: www.caissedesdepots.fr

[18] Available at http://ec.europa.eu/environment/ets

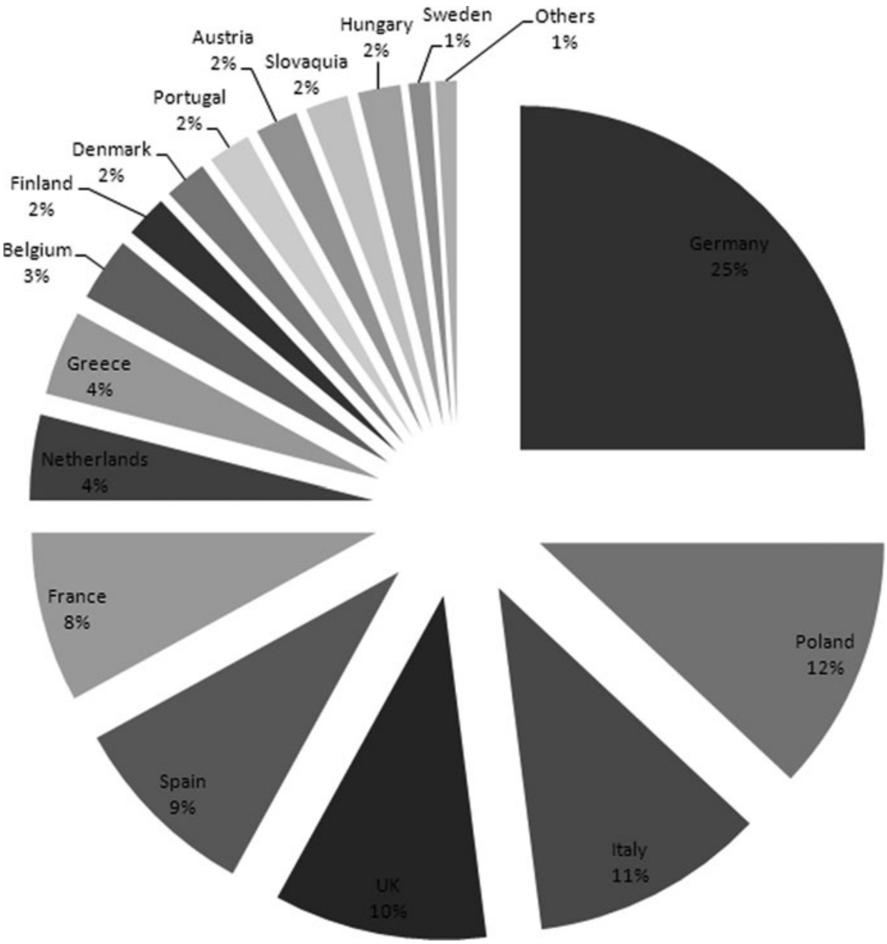

Fig. 1 EU ETS national allocation lans – phase 1 (2005–2007) (CITL 2007; CDC 2006)

generous allocations during the first phase of the EU ETS.[19] Surpluses also reflect to a limited degree reserves for new entrants, which are included in the data used.

Figure 4 takes a closer look at the allowance surpluses as a percentage of the allocation. It reflects a wide variety of cases among market participants as a conglomeration of countries (Poland, France, Finland, Denmark, Slovakia,

[19]Apart from the EU ETS, there is a need to be cautious here with the notions of "over allocating" and conversely "under-allocating" permits depending on the country. Their meaning depends on the reference point (business as usual plus some abatement for instance). If other trading schemes implement a per capita distribution for instance, it may appear less relevant to talk about "over allocation."

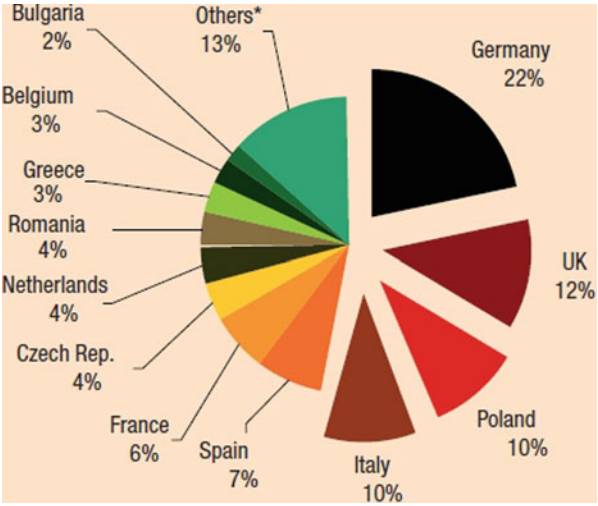

Fig. 2 EU ETS national allocation plans – phase II (2008–2012) (CITL 2008; CDC 2008)

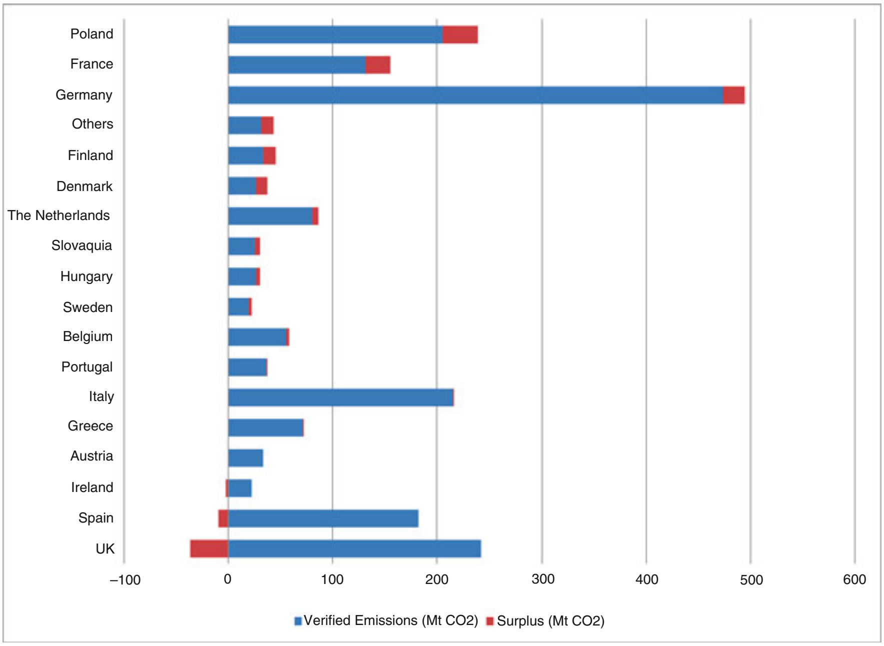

Fig. 3 Potential for market power by country (in absolute terms) (CITL 2007; CDC 2006)

Hungary) was able to build up a surplus of permits of more than 15%, while others (the UK, Ireland) are more than 15% short of permits.

The biggest player, Germany does not appear to be in a position to exert its market power with less than 5% of excess allowances. Poland's surplus should not

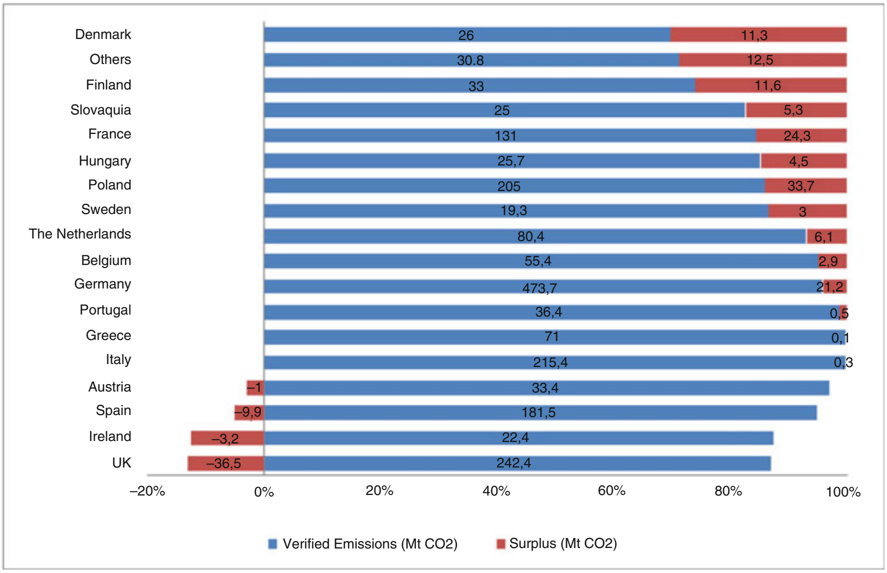

Fig. 4 Potential for market power by country (in percentage) (CITL 2007; CDC 2006)

be overstated either since the use of 10% of allowances is missing in the CITL. Portugal, Greece, Italy and Austria form a group of countries where the regulator strived to allocate permits optimally. On the contrary, stricter emissions reductions were enforced in the case of the UK, Ireland and Spain.

How could one explain those contrasting patterns in actual emissions for EU ETS participants in 2005? Part of the answer may be found in the decision making process within each National Allocation Plan (NAP). Godard (2003; 2005) describe the logic behind the French NAP when allocating shares of recent emissions baselines: non-electric utilities were supplied with their projected need for permits, while greater constraints were imposed upon electric utilities. This situation may be justified by the perceived abatement potential of the electricity industry, but overall reveals the necessary arbitrages to be made due to sector heterogeneity and a stringent cap.

As long as governments continue to allocate allowances to existing facilities based on historic emissions, the scheme will be flawed by a contrary "updating" incentive (Grubb and Neuhoff 2006). Indeed companies have no incentive to implement abatement technologies too early since higher emissions today will be rewarded with bigger allocations in future periods. Ellerman and Buchner (2008) provide a first empirical assessment of the EU ETS allocation process based on emissions data from 2005. They estimate a slight over-allocation of 4% during the first period of allocation, although there are strong signs that some emissions abatement measures have occurred. The analysis is not straightforward however since "a long position is not per se evidence of over-allocation." The difference between the 2005 allocation and verified emissions suggests that too many allowances were allocated, but the benchmark from which this conclusion is derived may be biased due to insufficient data reporting on emissions before 2005 and a lack of comparability measures at the EU-level. Companies may also be long because of differences in marginal abatement costs (MACs) or in expectations (regarding economic activity, energy prices, etc.) under uncertainty.

Overall, we can state that in the period from 2005 to 2007, the allowances that were allocated more than covered the verified emissions, with a net cumulated surplus of 156 million tons. This surplus however decreased from 83 million tons in 2005 to 37 million tons in 2006, and finally to 36 million tons in 2007. Emissions increased by 0.4% in 2007 compared to 2006, and reached 2,043 million tons compared to the 2,080 million allowances that were distributed.

Market power positions in the EU ETS should not solely be derived from analyses at the country level, but rather in conjunction with analyses at the installation level. For French installations subject to the Directive 2003/87/CE, an estimation based on 1,402 installations totaling 185.3 Mt CO_2 taken from the Register for Polluting Emissions (iREP)[20] revealed that almost 50% of permits were distributed to four players, with the first ten holders of permits accounting for 60% of permits accounting for the total allocation of permits.

Furthermore, Convery et al. (2008) point out a strong concentration of EU ETS installations, with 10% of 4,019 installations in surplus representing 75% of the total surplus (totaling 145 Mt) and 2% of installations representing 2% of the surplus.[21] Each of these big players might exert a dominant position in its own sector if permits are distributed freely based on recent emissions, as modeled in this chapter.

2.2.2 Prospective Use of Banking and Borrowing in the EU ETS

Member states have allowed banking and borrowing without restrictions within each compliance period. However, the possibility to carry over EUAs from the 2005–2007 period to the 2008–2012 period was restricted, even by France and Poland who allowed it to a certain extent in the first place.[22] A more detailed analysis of the consequences of banking banking from one period to another on the price of permits and the behavior of companies can be found in Alberola and Chevallier (2009). Moreover, preliminary analyses of the 2005–2007 data concerning the extent of the use of banking in the EU ETS can be found in Ellerman and Trotignon (2008) and Chevallier et al. (2008).

[20]The iREP is monitored by the Minister of the Environment and displays public information at www.pollutionsindustrielles.ecologie.gouv.fr/IREP/index.php

[21]Note however that Convery and Redmond (2007) compute a very low Herfindahl–Hirschman Index for the electricity-generating sector, which indicates an unconcentrated market. Thus, market observers are overall less wary of market power concerns in the EU ETS than in the KP, even if the Directive explicitly allows installations to "pool" allowances at the sector level.

[22]Permits that were bought cannot be banked. Besides, only "green" companies that have effectively reduced emissions may bank allowances in Poland.

This section provided an overview of two major markets for tradable permits along with their allocation methodology. It revealed a wide range of opportunities for strategic behavior in the design of international permit trading regimes. The presence of countries with large holdings of permits increases the probability of price manipulation and the risk of lower efficiency in the allocation of abatement efforts between countries. This background information is used as the basis for modeling a differential game with hierarchical play in this chapter.

3 The Model

This section outlines the features of the model. Firstly, the design of the cap-and-trade program is explained. Secondly, the industry and information structures are examined. Thirdly, an intertemporal constraint to emissions trading is defined and fourthly, the Hotelling conditions are described. Finally, the properties of the abatement cost function are explained.

3.1 Design of the Cap-and-Trade Program

The regulator sets a cap $\overline{E}$ on emissions of a given pollutant that corresponds to a specific environmental goal. The fix endowment is therefore exogenous to the model, and may be broken down into the individual allocation of permits $\overline{e_i}$ mandatory for each agent i.

Agents are split further into two types:

1. Agent $\{i = 1\}$ is a large polluting agent, who is initially allocated a large number of permits;
2. Agents $\{i = 2,\ldots, N\}$ aggregate many small polluting agents, who are assumed to be comparatively smaller holders of permits, belonging to the competitive fringe.

An agent may be a country, a company or a cartel.[23] The competitive market price is determined by the abatement costs of the fringe agents.

Market imperfection arises from the distribution of free permits on the basis of recent emissions.[24] The premise of the chapter is that the large agent may be able to

[23]For instance, within the KP permits may be exchanged from party-to-party, but also from company-to-company if Annex B members delegate this ability to private actors. In the third case, collusive behavior may arise either between parties or between companies (Liski and Montero 2005b).

[24]See Ellerman and Parsons (2006) for a review concerning the use of projections, benchmarking and intensity targets. While it is beyond the scope of this chapter to study the relative merits of grandfathering and auctioning, theoretical analyses stress the superiority of auctioning as in Jouvet et al. (2005). According to the Public Choice Theory, the free allocation of permits may also be seen by some companies as a means to extract more permits as a scarcity rent, and therefore lobbying takes place. However it also imposes liabilities on companies that are reflected in their

exert market power. I do not include the effects of incorporating a safety valve[25] into the model.

3.2 Industry Structure

This partial equilibrium model features an intra-industry permit market in a single good economy. I tend to neglect the interaction with the output market.

Market power is defined by Burniaux (1999) as "the capacity of a firm/country to influence the transaction price of traded permits" (referred to as a "cost minimizing manipulation"). Therefore, I do not address exclusionary manipulation strategies[26] that occur when the dominant agent uses its market power on the permits market to raise entry barriers or exclude agents on the output market.

3.3 Information Structure

A differential game[27] played in continuous time was modeled where all players have the possibility of influencing the rate of change of the permits bank through their current actions. It is therefore assumed that they adopt a Markovian strategy.

The common knowledge includes the fact that all players need to comply with the environmental constraint that is exogenously set by the regulator. The game unfolds in two steps. Firstly, the follower's reaction function is derived from any action announced by the leader through the fringe agents' cost minimization problem at the competitive price. Secondly, it is observed how the leader might exercise market power as a large agent integrates the reaction function into his own cost minimization problem, and decides how to adjust his emissions level. All other parameters are kept constant.[28]

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balance sheets. As highlighted by Raymond (1996), the initial allocation of permits reveals social norms embedded by newly created permits. The free distribution of permits may be seen as an entitlement to an environmental resource. As conceptions evolve and auctioning might become predominant, the question arises as to whether the probability of achieving a dominant position will increase or decrease.

[25]A safety valve may be defined as a hybrid instrument to limit the cost of capping emissions at a certain target level, whereby the regulator offers to sell permits in whatever quantity at a pre-determined price.

[26]See Misiolek and Elder (1989).

[27]See Dockner et al. (2000) for an overview of differential games.

[28]For instance, agents do not incur information costs.

3.4 Intertemporal Emissions Trading

Agents may bank and borrow permits without restrictions. Let $B_i(t)$ be the permits bank, with $B_i(t) > 0$ in case of banking, and $B_i(t) < 0$ in case of borrowing.

Any change in the permits bank is equal to the difference between $\overline{e_i}(t)$ and $e_i(t)$, respectively an agent's i permit allocation and his emission level at time t. The banking and borrowing constraint may be written as

$$\dot{B}_i(t) = \overline{e_i}(t) - e_i(t) \tag{1}$$

with $B_i(0) = 0$ as an initial condition.

3.5 Hotelling Conditions

Notwithstanding differences between a permit and an exhaustible resource,[29] it is assumed in the literature that the Hotelling conditions for exhaustible resources must apply on a permits market. Consequently, the terminal and exhaustion conditions are detailed below.

3.5.1 Terminal Condition

Let [0, T] be the continuous time planning horizon.[30] At time T, cumulated emissions must be equal to the sum of each agent's depollution objective and therefore to the global cap $\overline{E}$ set by the regulator[31]:

[29]According to Liski and Montero (2006), the following differences may be highlighted. First, in a permits market with banking, the market still remains after the permits bank has been exhausted; while the market of a non-renewable resource vanishes after the last unit of extraction. Secondly, permits extraction and storage costs are equal to zero; while those costs are generally positive for a non-renewable resource. Thirdly, the demand for an extra permit usually comes from the demand derived from other companies that also hold permits; while the demand for an extra unit of a non-renewable resource more often comes from a demand derived from another actor (e.g., a consumer).

[30]This planning period seems appropriate for a theoretical study of intertemporal emissions trading. Alternative time settings including distinct phases may be found in Montero and Ellerman (1998), Schennach (2000) or Ellerman and Montero (2002), but they reflect the specific requirements of the Acid Rain Program (USA).

[31]See also Leiby and Rubin (2001).

$$\int_0^T \sum_{i=1}^{N} e_i(t)dt = \sum_{i=1}^{N} \overline{e_i} = \overline{E} \quad (2)$$

3.5.2 Exhaustion Condition

At time T, there is no more permit in the bank (either stocked or borrowed):

$$\sum_{i=1}^{N} B_i(T) = 0 \quad (3)$$

These conditions ensure that agents gradually meet their depollution objective so that the marginal cost of depollution is equalized at the current value over the time period, and the permit bank is cleared in the end.

There is typically a truncation problem at the end of the period:

- if $B_i(T) > 0$, surplus allowances are worthless and agents waste their permits;
- if $B_i(T) < 0$, agents need to pay a penalty.[32]

3.6 *Abatement Cost Function*

Let $C_i[e_i(t)]$ be the abatement cost function[33] incurred by agent i in order to comply with his allocation of permits $\overline{e_i}$. $C_i[e_i(t)]$ is defined on $\Re \to \Re$continuously and is of class $C^2[0, T]$, i.e. twice continuously differentiable. The classical assumption[34] of strictly increasing abatement costs leads to $C_i[e_i(t)]$ being convex, with $C_i^{'}[e_i(t)] < 0$ and $C_i^{''}[e_i(t)] > 0$. $C_i[e_i(0)]$ can be set to 0.

An agent's i MACs are associated with a one-unit reduction from his emission level e_i at time t, and are noted as $-C_i^{'}[e_i(t)] > 0$. At the equilibrium of a permits market in a static framework,[35] price-taking agents adjust emissions until the aggregated MAC is equal to the price P at time t:

[32]For instance, the penalty is equal to 40€ and 100€ per unit plus a compensating allowance for the first two periods of the EU ETS, and can add up to 40% of additional emissions during the first period of the Kyoto Protocol.

[33]Compared to a situation where profits are unconstrained, abatement costs are introduced in order to meet the emission cap.

[34]Stated first by Montgomery (1972). The conditions given by Leiby and Rubin (2001) include the output $q(t)$ where $C_i[q_i(t), e_i(t), t]$ is strongly convex with $C_i'[q_i(t)] > 0$ and $C_i''[q_i(t)] > 0$. Properties of non-convex abatement cost functions may be found in Godby (2000).

[35]See Hahn (1984).

$$P_t = -C_i'[e_i(t)] \tag{4}$$

4 The Stackelberg Game

In what follows, the dominant agent sets the price at a level, which corresponds to the maximization of the difference between revenues from the sale of permits and its abatement costs. All other agents behave as price takers, i.e. they minimize their abatement and trading costs given the permit price set by the dominant agent. It is interesting here to evaluate how the dominant agent will set the permit price higher and abate less (or sell fewer permits) compared to the competitive solution. This differential game with hierarchical play is solved by backward induction.

4.1 The Fringe Agents' Reaction Function

The first step of the game is concerned with developing the strategy of the fringe. Fringe agents choose their optimal emissions level according to the possibility of banking and borrowing permits in constraint (1). The cost minimization program may be written as follows:

$$\begin{cases} \min\limits_{e_i} \int\limits_0^T e^{-rt}\{C_i[e_i(t)] + P(t)[e_i(t) - \overline{e_i}(t)]\}dt \\ \dot{B}_i(t) = \overline{e_i}(t) - e_i(t) \\ B_i(0) = 0 \\ C_i[e_i(0)] = 0 \end{cases}$$

Two possible forms of the fringe agents' reaction function $P_t = -C_i'[e_i(t)]$ and $P_t = -C_i'[e_i(t)] + \lambda(t)$ may be highlighted depending on the net banking/borrowing position of fringe agents at the end of the period. See Chevallier (2008) for the formal resolution of this optimization program.

In the next step the large agent's behavior is incorporated and how he integrates the two possible cases of reaction function into his own optimization program.

4.2 Behavior of the Dominant Agent

In the second step of the game, the first-order conditions of the fringe problem are used as the constraints in the leader's problem. The large agent strategically adjusts his optimal emissions levels according to its initial allocation $\overline{e_1}$ as expressed by (2) and the banking borrowing constraint (1). The cost minimization program for agent $\{i = 1\}$ is

$$\begin{cases} \min_{e_1} \int_0^T e^{-rt}\{C_1[e_1(t)] + P_t[e_1(t) - \overline{e_1}(t)]\}dt \\ \dot{B}_1(t) = \overline{e_1}(t) - e_1(t) \\ \overline{E} = \int_0^T e_1(t)dt + \int_0^T \sum_{i=2}^N e_i(t)dt \\ B_1(0) = 0 \\ C_1(0) = 0 \end{cases}$$

By replacing P_t with both forms of the fringe agents' reaction function as shown above, it is possible to identify the following price distortion condition[36]:

$$-C_1'[e_1(t)] = P(t) + \left[1 + \varepsilon_i \sum_{i=2}^N e_i(t)\right] \tag{5}$$

The large agent's MAC is equal to the competitive permits price plus an element of price distortion ε_i defined as the fringe agents' elasticity:

$$\varepsilon_i = \frac{C_i''(e_i)}{C_i'(e_i)} = \frac{dC_i'}{dC_i} \tag{6}$$

Thus, a manipulation of the price of permits results in higher total abatement costs than under perfect competition. Market power is a function of the fringe agents' elasticity and of the large agent's number of permits:

$$\varepsilon_i = \sum_{i=2}^N e_i(t) = \varepsilon_i[e_1(t) - \overline{e_1}(t)] \tag{7}$$

Due to the convexity assumption, the fringe agents' elasticity is negative, and emphasizes the possibility for the leader to negatively affect the fringe agents' behavior. The large agent's MAC is *lower* than under perfect competition. Since he enjoys a dominant position and has the ability to influence the price of permits, the large agent may be characterized overall as a net gainer and the fringe agents as net losers.

In either case where both agents have a net banking or borrowing position in the terminal period, the large agent is able to negatively affect the fringe agent's MAC through the number of permits he holds in excess of his emissions. This condition holds when both agents clear their permits bank in the terminal period, whereby

[36]See Chevallier (2008) for the formal resolution.

the large agent is still able to negatively affect the fringe agent's MAC. One can therefore confirm the possibility of strategic manipulation for both forms of the fringe agents' reaction function.

In the next section, numerical simulations are provided to illustrate these results.

5 Numerical Simulations

This section attempts to provide quantitative estimates of the degree of price distortions induced by dominant behavior on existing emissions trading schemes. More precisely, data on MAC curves is used provided by Decaux and Ellerman (1998) using the MIT EPPA model, and Loschel and Zhang (2002) using the world energy system model POLES (Criqui et al. 1996) to simulate the effect of a price distortion condition as shown individually in (5)–(7).

On the one hand, the MAC cost curves given by Decaux and Ellerman (1998) have the following functional form:

$$Y = \alpha X^2 + \beta X \tag{8}$$

where Y is the marginal cost of carbon in 1985 in US\$, X is the extent of abatement in million metric tons of carbon (Mton), and where α and β are parameters.

On the other hand, Loschel and Zhang (2002) kept the following specification:

$$Y = \alpha(X)^{\beta} \tag{9}$$

where Y is the MAC, X is the amount of abatement, and where α and β are parameters.

Several scenarios may be used in order to derive numerical estimates of the market power condition. In what follows, a situation is simulated where Foreign Soviet Union countries form a cartel, and attempt to distort the prices based on the *Hot Air* created by the political market imperfection at the negotiation stage of the Kyoto Protocol.

The values given for all parameters are displayed in Tables 3 and 4. Plugging these values into the price distortion condition (5), the following results are obtained:

From Tables 3 and 4, quantitative estimates are obtained on the degree of price distortions induced by the Stackelberg game. It is indeed striking to observe that, based on data provided by Decaux and Ellerman (1998), price distortions and efficiency losses based on the fringe agents' elasticities and the large agent's permit endowment range from 13% to 35% in the context of the *Hot Air* discussion underlying the Kyoto Protocol. These estimates are even wider when based on the data from Loschel and Zhang (2002), ranging from 33% to 229%. Notwithstanding the presence of outliers in our numerical simulations, these results globally illustrate the risk of market power and associated economic inefficiencies due to the initial allocation of emission rights, as pointed out by Hahn (1984).

Table 3 Simulated price distortions based on data provided by Decaux and Ellerman (1998) (Adapted from Decaux and Ellerman 1998)

Country	α	β	X	MAC′/MAC	$e_i - \overline{e_i}$	P_t	Price distortion (%)
USA	0.0005	0.0398	571	0.0033	571	127	−7.23
JAP	0.0155	1.8160	144	0.0108	144	127	−23.70
EU	0.0024	0.1503	308	0.0059	308	127	−13.08
OECD	0.0085	−0.0986	171	0.0121	171	127	−26.67
EUC	0.0079	0.0486	122	0.0160	122	127	−35.20
FSU	0.0023	0.0042	−110	−0.0183	−110	127	

The price distortion is computed using (5)–(7)*USA* United States, *JAP* Japan, *EU* European Union, *OECD* member countries of the organisation for economic co-operation and development, *EUC* Eastern European countries, *FSU* Foreign Soviet Union countries

Table 4 Simulated price distortions based on data provided by Loschel and Zhang (2002) (Adapted from Loschel and Zhang 2002)

Country	α	β	X	MAC′/MAC	$e_i - \overline{e_i}$	P_t	Price distortion (%)
AUN	0.6750	1.4420	24	0.0601	15.6	65.9	−150.93
JAP	0.7180	1.3380	29.3	0.0457	18.5	65.9	−114.71
EU	0.1140	1.3690	104.1	0.0132	66.4	65.9	−33.03
CAN	1.5670	1.3790	15.1	0.0913	9.6	65.9	−229.41
FSU	0.0460	1.4820	−125.6	−0.0118	−125.6	65.9	

The price distortion is computed using (5)–(7)*AUN* Australia and New Zealand, *JAP* Japan, *EU* European Union, *CAN* Canada, *FSU* Foreign Soviet Union countries

However, the specter of a large agent achieving a market power position may be averted by a careful design of the cap-and-trade program. As illustrated by the ongoing debate on the EU ETS NAPs, there is a need for further research to assess the best solution for allocating permits efficiently (whether this be through output-based methods, benchmarking, minimum price auctioning, etc.).

6 Conclusion

The description of the institutional framework on which the model hinges provided a balanced picture of market power concerns in existing international emissions trading schemes. As for the Kyoto Protocol and trading rules in the making, projections preclude from reaching a definitive conclusion; however our analysis also reveals the possibility of moving an international permits market in a dynamic context. A global conclusion concerning EU ETS market power concerns gears towards a prudent approach: if some firms have received more permits than projected, they might very well end up with a shortage of permits at the end of the first period because of an increase in emissions. The EU Commission is particularly careful when validating NAPs for their stringency and the fact that there will be no *ex-post* adjustment. Still, there are strong signs of concentration at the installation level. Both schemes allow a full banking and borrowing intra-period.

To capture the distortions induced by initial allocation, a differential game was introduced where agents differ in terms of their exogenous permit endowment and a Markovian strategy was adopted. The main result consists in a price distortion condition based on the fringe agents' elasticity and the large agent's permits endowment that explains how the large agent is able to negatively affect the fringe agents' MACs. In both cases where agents either compensate their net banking/borrowing positions or clear their permits bank at the end of the period, it is possible to identify *net losers* (i.e., fringe agents) and a *net gainer* (i.e., the large agent) as the large agent benefits from a *lower* MAC than it would do under perfect competition.

Since the price set by the dominant agent directly depends upon the amount of permits initially allocated to that agent, this chapter contributes to the link between distributional aspects and the overall efficiency of tradable permit markets. It extends Hahn's analysis from Hahn (1984) on market power in a dynamic framework and builds upon Liski and Montero (2005b, 2006) by modeling strategic interactions after a Stackelberg game and providing a full characterization of the effects of unrestricted banking and borrowing. The numerical simulations computed for the price distortion condition based on data from Decaux and Ellerman (1998) and Loschel and Zhang (2002) provide a quantitative illustration of the results obtained. They also reveal the magnitude of the economic inefficiencies induced by the initial allocation of emission rights.

However, the spectre of market power need not arise if the cap-and-trade program appears properly designed. The negotiation process of each NAP at the Member State level is typically an example of a manipulable rule whereby industries may conduct lobbying activities to extract more permits as a monopoly rent. With reference to the debate "rules vs. discretion" in monetary economics, this unhealthy lobbying on behalf of major industries calls for further research to ascertain the conditions under which it would be optimal to delegate the determination of the cap and the distribution of permits to an independent agency (Helm et al. 2003; Grubb and Neuhoff 2006).

The model could be extended by the adoption of an intertemporal trading ratio specific to borrowing as discussed by Kling and Rubin (1997),[37] allowing for a better understanding of the possibilities presented by intertemporal emissions trading. It may also be interesting to look at another source of heterogeneity between agents, for instance based on their emissions reduction function.

As a final comment, one could say that a greater reliance on banking and limited borrowing (i.e., with a specific discounting factor) should be promoted to allow firms to smooth their emissions and make investment decisions on abatement technologies with a better capacity to react to the evolution of the carbon constraint over time.

[37]The adoption of a discount rate penalizing borrowing may remove some of the perverse incentives whereby agents concentrate emissions on early periods, which is not socially optimal.

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