WORKING PAPERS IN ECONOMICS

No. 05/05

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STRATEGIC MARKETS IN PROPERTY RIGHTS WITHOUT PRICE-TAKERS

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Strategic markets in property rights without price-takers

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Abstract

Cournot-type models of markets in property rights typically feature strategists—acting at a first stage—followed by the move of a *non-empty* market-clearing competitive fringe. So, which agents can presumably be assigned the price-taking role? When simulating the upcoming medium-sized market for greenhouse gas emissions permits under the Kyoto Protocol, no answer to this question stands out as satisfactory. As an escape, trade is instead construed as a two-stage noncooperative cooperative game in which all agents act on both stages, allowing everyone to be a strategist.

Keywords: Cournot oligopoly, competitive fringe, market games, property rights, emissions trading, Kyoto Protocol.

1 Introduction

Accommodated here is a fixed and finite set of economic agents, seen as producers. Each among them owns perfectly divisible transferable property rights, say emissions permits, regarded as valuable production factors. These are exchanged in a common market under a well defined price. The upcoming market for greenhouse gas emissions permits under the Kyoto Protocol [14] serves as my motivation and running story. Most simulations of that agreement suggest that trade will occur between relatively few parties (Springer [13] reviews relevant studies).

Suppose therefore, in contrast to Montgomery [9], that at least one agent uses his net supply/demand to manipulate the equilibrium price as done in models à la Cournot. Then:

• *What sort of equilibrium applies to this type of markets?* And, more specifically,

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• *What may we expect from the permit market under the Kyoto Protocol in terms of prices and quantities?*

The work-horse model of imperfect markets in transferable property rights was introduced by Hahn [7] allowing for *one* dominant firm. The extension to oligopoly was carried out by Westskog [15]. In these studies trade is construed as a Stackelberg-type two-stage game featuring two sorts of players: *strategists* and *price-takers.* Strategists decide right away the amount of permits they want to use. Thereafter, their choices leave the price-taking fringe to allocate among themselves what remains available. Allocation there emerges via a market governed by a clearing price. The strategists foresee how their choice of quantity affects the said price; price-takers do not. In other words: strategists—and they only—play against an endogenous "price curve" generated by the fringe.[1]

Obviously, this model does not allow everyone to be strategic. Absent price-takers, there is no market clearing device. So, who can reasonably qualify as bona fide fringe members? A first hunch indicates that agents who trade relatively small quantities do indeed. And hopefully, it should also make little difference whether a "negligible" agent is modeled with the other mode of behavior. As it turns out, the said hope is not well funded. To wit, if a single small player were to change his behavioral mode, the effect on equilibrium can be substantial. In other words, equilibrium, if unique, may be unstable/jumpy with respect to the classification of players.

Plainly, the resulting instability of solutions is worrisome and challenging. It leads me to model trade as a two-stage game where *all* agents—strategists or not—take part at *both* stages. First, all agents decide noncooperatively on the amount of permits to bring to a second stage (cooperative) market game. There, and once again, all agents participate and permits are shared in a cooperative manner that yield core solutions. A strategist accounts for how his first stage choice affects the outcome of the second stage game—price-takers, if any, do not. This approach is based on Flåm and Jourani [4], whose running story depicts a regional oligopoly, embodying transportation as a second-stage production game. Adaptation to permit markets was introduced by Flåm and Godal [2] and is somewhat modified and further developed here below.

The alternative approach has several noteworthy features: First, it predicts the same results as Montgomery [9] and Hahn [7] in the two polar instances of perfect competition and monopoly/monopsony respectively. Second, even though perfectly competitive behavior at the first stage can be exogenously assigned to any agent, *all* agents may come forward as strategists. Third, whether a "small" agent is modeled with market power or not, does not much affect equilibrium. Fourth, it

[1] This feature differs from the classic Cournot model in which the inverse demand function is exogenous. Another distinction is that here, it is endogenously determined whether an agent comes forward as a supplier or demander - and strategic agents may be present on both sides of the market. In these respects, the setting here resembles that of strategic multilateral exchange, as in Gabszewicz [5] and Giraud [6].

appears that should more than one strategist be around, more trade occurs in the alternative approach as compared to the traditional framework.

The rest of the paper is organized as follows. Section 2 revisits the model of strategic permit trade proposed by Hahn [7] and extended by Westskog [15]. Worried about who belongs to the fringe, I present some simulations of permit trading under the Kyoto Protocol using that model choosing various configurations of price-takers and strategists. That exercise motivates Section 3, where the alternative model is spelled out together with more simulations. Section 4 provides some remarks on how the two approaches compare, while Section 5 models permit trading among those parties that have ratified the Kyoto Protocol when it entered into force on February 16$^{\text{th}}$ 2005. Section 6 offers a concluding remark.

2 The Hahn-Westskog framework

2.1 Model

Let I be the fixed and finite set of economic agents who set out to keep aggregate emissions of a certain gas below a specific level, carbon dioxide being a case in point. Each agent $i \in I$ is endowed with e_i permits that are homogeneous, perfectly divisible, non-storable and exchanged in a common market at unit price $p > 0$. Agent $i \in I$ decides to use amount x_i for himself and thereby incur emission cost $c_i(x_i)$. It is natural to assume c_i decreasing convex. For analytical convenience I also take c_i to be twice continuously differentiable with $c_i' < 0$ and $c_i'' > 0$.[2]

There are two types of agents. Each $i \in I$ comes forward either as a price-taker, and thereby belongs to a *non-empty* competitive fringe named $F \subseteq I$, or he uses his market power, thereby belonging to a possibly empty set $S := I \backslash F$ of strategists. Agents interact as if there were two stages. First, each strategist $i \in S$ chooses the amount of permits he wants to retain for himself. At the second stage, the fringe allocates what remains available via perfect competition. Thereby, the fringe supposedly acts as though solving the problem

$$c_F(Q) := \min_{\mathbf{x}_F} \sum_{i \in F} c_i(x_i) \text{ subject to } \sum_{i \in F} x_i \leq Q \tag{1}$$

where $Q := \sum_{i \in I} e_i - \sum_{i \in S} x_i$ is the amount of permits available to the fringe, and $\mathbf{x}_F := (x_i)_{i \in F}$ the permit allocation across members of the fringe.

[2] Flåm and Godal [3] generalize the model in this section to: 1) allowing for more than one gas, 2) adopting less restrictive (and more realistic) assumptions about the properties of the cost functions and 3) explicitly accounting for technological constraints, such as non-negativity. The model in the subsequent section may be modified to account for surch features as well.

Furthermore, for other markets in property rights, say harvesting quotas for fish, it may be more natural to speak of an increasing and concave payoff function $\pi_i(x_i)$ stemming from the use of x_i rather than the cost function used here. In such settings, the below analysis applies by letting $c_i(x_i) := -\pi_i(x_i)$.

The market clearing price p emerges as the shadow price associated with the constraint in (1). The strategists recognize that the said price depends on their choice x_i through Q and each among them seeks to

$$\text{minimize } \{c_i(x_i) + p(x_i - e_i)\} \tag{2}$$

with respect to x_i, $i \in S$. If an equilibrium exists, it satisfies

$$\begin{array}{l} -c_i'(x_i) = p \text{ for all } i \in F, \sum_{i \in F} x_i = Q, \text{ and} \\ -c_i'(x_i) = p + p'(x_i - e_i) \text{ for all } i \in S, \end{array}$$

where, by the envelope theorem, $p = -c_F'(Q)$. Moreover, as $-c_i'(x_i) = p$ for all $i \in F$ in equilibrium, and since $c_i''(x_i)$ is non-zero, there exists (by the implicit function theorem) a continuously differentiable function g_i for all $i \in F$ such that $g_i(p) = x_i$ where $g_i' = \frac{1}{c_i''(x_i)}$. Combining this with the market clearing constraint and the definition of Q, it then follows that in equilibrium, for all $i \in S$

$$p' := \frac{\partial p}{\partial x_i} = \frac{1}{\sum_{i \in F} \frac{1}{c_i''(x_i)}}. \tag{3}$$

Since $c_i'' > 0$, it follows that $p' > 0$. This confirms intuition: the more permits a strategist use, the less is available for the fringe, and the higher the clearing price. A second observation is that the slope of inverse demand depends on the *curvature* properties of the cost functions for the price takers. Keeping in mind that $(x_i - e_i)$ in (2) can be positive or negative, depending on whether a strategist buys or sells, it is difficult to establish convexity in the objective function for the strategist, a most desirable property to guarantee that an equilibrium in fact exists.[3]

2.2 Simulations

Equipped with the Hahn-Westskog model, what may be expected from the Kyoto Protocol in terms of prices and costs if some parties act strategically in the permit market? The Kyoto agreement of 1997, which concerns emissions of greenhouse gases that appear to contribute to climate change, specifies endowments of permits to the governments of most industrialized countries for the period 2008-2012. Article 17 therein, allows parties to comply via emissions trade [14].

To model this upcoming market, emissions cost functions were derived from the MERGE model developed by Manne and Richels [8] (See Appendix I for details). However, in order to apply the Hahn-Westskog model it is necessary to pick some price-takers. For that purpose, a simulation of the perfectly competitive equilibrium

[3] Sufficient conditions for existence and uniqueness of equilibrium in this model are provided in Flåm and Godal [3]. It appears that the commonplace assumptions on the properties of the cost functions that also are adopted here, are neither necessary, nor sufficient.

shall serve as a benchmark, so to identify any agents with a potential dominant position in this market. The results are as follows:[4]

Table 1. Perfectly competitive permit trading under the Kyoto Protocol.

	Emissions	Permits bought	− marg. cost	Costs	Market share
Symbol	x_i	$x_i - e_i$	$-c_i'$	TC_i	α_i
Units	MtC/yr	MtC/yr	USD/tC	BUSD/yr	
US	1559.1	309.1	141	61.6	61.2 %
Russia	464.9	-303.1	141	-39.1	-60.0 %
EU-15	935.0	96.0	141	18.9	19.0 %
Ukraine	137.9	-90.1	141	-11.6	-17.8 %
Japan	322.3	64.3	141	11.1	12.7 %
Poland	74.7	-41.3	141	-5.2	-8.2 %
Canada	150.8	27.8	141	6.6	5.5 %
Czech Rep.	32.5	-18.4	141	-2.3	-3.7 %
Romania	33.8	-17.6	141	-2.2	-3.5 %
Bulgaria	16.5	-8.6	141	-1.1	-1.7 %
Hungary	14.0	-7.8	141	-1.0	-1.5 %
Slovakia	12.2	-6.3	141	-0.8	-1.3 %
Australia	90.2	5.4	141	2.4	1.1 %
Lithuania	7.7	-4.1	141	-0.5	-0.8 %
Estonia	7.4	-3.9	141	-0.5	-0.8 %
Latvia	4.9	-2.5	141	-0.3	-0.5 %
Slovenia	2.7	-1.4	141	-0.2	-0.3 %
Switzerland	12.5	1.3	141	0.3	0.3 %
New Zealand	8.2	1.1	141	0.3	0.2 %
Norway	9.9	0.2	141	0.1	0.0 %
Iceland	0.6	0.0	141	0.0	0.0 %
Total	3898	0.0		36.3	505.2

Each agents market share α_i, given in the right column of Table 1, is defined as $(x_i - e_i)/V$ with $V := \frac{1}{2}\sum_{i\in I}|x_i - e_i|$ being the volume of the permit market given in the coordinate Total/α_i. Thus, a positive (negative) α_i signifies that the agent comes forward as a buyer (seller) of permits in equilibrium respectively. Total costs TC_i, is the number $c_i(x_i) + p(x_i - e_i)$. The rows in Table 1 have been sorted according to the absolute value of the market share. Hence, the most dominant actor in the market is the US, purchasing about 61% of all permits bought, closely followed by Russia who is contributing with about 60% of the total permit supply.

Clearly, the market shares displayed in Table 1 indicate that assuming all agents to appear as price-takers can hardly be defended. But who qualify as strategists?

[4] In the proceeding tables, I use the following abbreviations: M—million, B—billion, t—metric ton, C—carbon, USD—US dollars of 1997 and yr—year.

The US and Russia only? Should the EU, Ukraine and Japan be modeled with this kind of behavior as well?

Intuitively one would believe that if someone were to qualify as a price-taker, it should make little overall difference had he rather been modeled as a strategist. Since it appears more reasonable that an agent that trades more, rather than little, has a greater potential to manipulate the market, I shall construct a sequence of simulations with the perfectly competitive equilibrium as a point of departure. First, the market is re-model with assuming the US to make use of its market power instead of being a price-taker. Next, Russia is included in the set of strategists, then the EU and so on. The hope is that at some stage, it does not matter any more which mode of behavior an agent supposedly takes, and that this happens before the fringe is emptied. How the permit price changes in this sequence of simulations is displayed in Figure 1.[5]

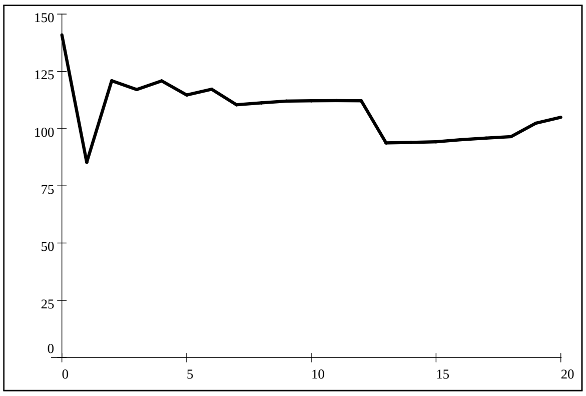

Figure 1. The permit price as the number strategists increases. USD per ton carbon.

Figure 1 shows that the permit price drops from 141 to about 85 USD per ton carbon when the US appears as a monopsonist. When Russia, a major permit supplier, is moved from the fringe to the strategic set, the permit price is higher. The subsequent price changes as more agents are modeled as strategists are less substantial.

However, when it comes to the traded volumes, this result is no longer maintained.

[5] The data behind all upcoming graphs are obviously discontinuous. The dots have been connected to improve presentation. The numbers reflect prices and quantities that satisfy the first order optimality conditions.

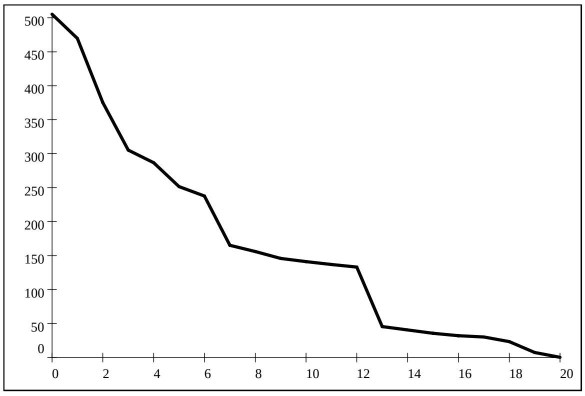

Figure 2. The volume of the market as the number strategists increases. Million tons carbon per year.

Figure 2 demonstrates that the amount of permits traded vanish as the number of price-takers approaches one. When the US is modeled as a strategist alone, about 35 million tons of carbon are pulled out of the market as compared with the case of perfect competition. When a much less active trader, Australia, enters as the twelfth strategist, the amount of permits that vanish from the market is about 87 million tons of carbon.

It appears that the main explanation for this result is due to the change in the slope of the "price curve" given in (3), as more agents are assumed to make use of market power. Large parties like the US and Russia, typically have a relatively small $c_i''(x_i)$ since emissions reductions can be spread over a larger economy, than say in Australia. Therefore, if the latter country for some obscure reason was the only agent to act strategically, it would not change the slope of the price curve substantially. However, when the large parties already are modeled as strategists, it becomes more important what sort of behavioral mode a "small" country like Australia supposedly adopts, since that country then becomes "large" as compared to the remaining agents in the fringe.

Not surprisingly, the development of total costs across all agents (a negative measure of welfare) as the number of strategists increase follows a mirrored pattern.

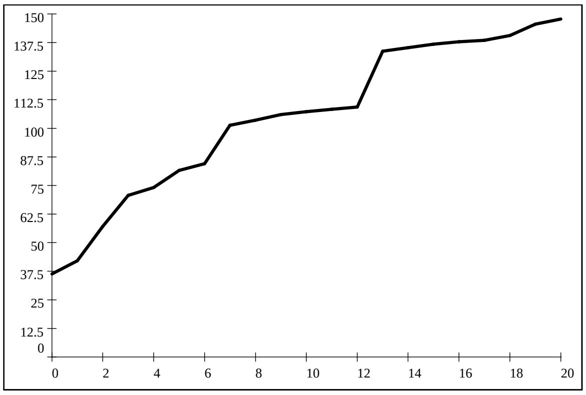

Figure 3. Total costs across all agents as the number strategists increases. Billion USD per year.

Compared to the perfectly competitive equilibrium, total costs are about 4-folded as a result of strategic behavior on behalf of all but one party (Iceland), which essentially is the cost of the agreement without any trade.

Returning to "Who can be modeled as price-takers"? From Figures 2 and 3, a reasonable criterion to distinguish price-takers from strategists in this "medium-sized" market appears to be absent. This motivates what follows next.

3 An alternative approach

3.1 Model

The agents, endowments and cost functions are as in the previous section. What differs now is the structure of the game. There are two stages also here, but at the first stage each agent $i \in I$ (not merely the strategists) decide noncooperatively the amount z_i he will bring to a second stage. There, and once again, *all* agents (as opposed to merely the price-takers) decide in a cooperative manner how to share whatever was brought.[6]

Therefore, at the second stage, every agent $i \in I$ participates, and each among them may join a coalition $M \subseteq I$. Should this coalition form, having $z_M := \sum_{i \in M} z_i$

[6] In contrast to Flåm and Godal [2], agents will here be allowed to bring more than their endowment to the second stage. Hence, e_i is not taken as an upper bound on the choice z_i. Although such constraints may be cared for, they would presumably become binding for strategic agents who come forward as buyers, since they would want to contribute to lowering the second stage price. If including such constraints, it appears that strategic buyers cannot adopt a better strategy than those of a price-taker; namely to bring precisely the endowment to the second stage game. I find it more appealing to let strategist play on equal footing regardless of whether they are relatively well- or poorly endowed. Hence, the absence of such constraints.

available for joint use, it cannot incur lower costs than

$$C_M(z_M) := \min_{\mathbf{y}_M} \sum_{i \in M} c_i(y_i) \text{ subject to } \sum_{i \in M} y_i \leq z_M \tag{4}$$

where y_i is the amount of permits agent i receives at this stage, and $\mathbf{y}_M := (y_i)_{i \in M}$.

Following Shapley and Shubik [12] this construction defines a cooperative market game with player set I and characteristic function $M \mapsto C_M(z_M)$. Efficiency and stability for such games are described by core solutions. That is, the cost allocation $(co_i)_{i \in M}$, where agent $i \in M$ pays the monetary amount co_i, belongs to the core if, and only if, it satisfies

$$\begin{array}{llll} \textit{Pareto efficiency:} & \sum_{i \in I} co_i & = & C_I(z_I), \text{ and} \\ \textit{social stability:} & \sum_{i \in M} co_i & \leq & C_M(z_M) \text{ for every } M \subset I. \end{array}$$

Social stability guarantees that no single agent or coalition $M \subset I$ could lower its costs by splitting away and play on their own. In absence of the Pareto efficiency requirement, social stability can easily be ensured. To satisfy both, associate the Lagrangian

$$L_I(r, \mathbf{y}_I) := \sum_{i \in I} \left[c_i(y_i) + r(y_i - z_i)\right]$$

to problem (4) for the grand coalition $M = I$, where r is a Lagrange multiplier. Then, according to Evstigneev and Flåm [1], the cost allocation

$$co_i := \min_{y_i} \{c_i(y_i) + r(y_i - z_i)\} \tag{5}$$

will belong to the core if r is a shadow price.

Without other justification than simplicity, I assume that this particular (competitive) element of the core is the one that will be agreed upon at this stage, and more demandingly, that this is commonly understood at the first stage.

There, each agent $i \in I$ chooses the amount z_i that he brings to the second stage. I suppose he does so in order to minimize his final costs, that is, he acts as if solving

$$\min_{z_i} \{c_i(e_i - z_i + y_i) + r(y_i - z_i)\} \tag{6}$$

where each price-taker (if any) treats r and y_i as independent of z_i, while each $i \in S$ fully accounts for such dependencies.

Once again, it appears difficult to rule out potential non-convexities in the objective function in (6) with respect to z_i. The reason being that r is a function of z_i (acknowledged by the strategists) which can have undesirable curvature properties. I shall ignore such problems here and instead assume an equilibrium to exist. When it does, it satisfies

$$\left.\begin{array}{l} -c_i'(e_i - z_i + y_i) = r \text{ for all } i \in F, \ \sum_{i \in I} y_i = z_I \text{ and} \\ -c_i'(e_i - z_i + y_i)(1 - y_i' r') = r(1 - y_i' r') - r'(y_i - z_i) \text{ for all } i \in S \end{array}\right\} \tag{7}$$

where by the same arguments as in Section 2,

$$
\begin{aligned}
r &= -C_I'(z_I), \\
r' &:= \frac{\partial r}{\partial z_i} = -\frac{1}{\sum_{i\in I}\frac{1}{c_i''(y_i)}}, \qquad (8) \\
y_i &= -(c_i')^{-1}(r)
\end{aligned}
$$

and

$$
y_i' := \frac{\partial y_i}{\partial r} = -\frac{1}{c_i''(y_i)}. \qquad (9)
$$

From these first order conditions the following result is obtained.[7]

Proposition 1 (On what characterizes price-taking and strategic behavior) *Suppose there exists an equilibrium in the first stage noncooperative game. Then,*
(i) all price-takers bring along precisely their endowment to the second stage game and their final marginal abatement cost, $-c_i'(x_i)$, equals the permit price. Furthermore,
(ii) the following are equivalent: A strategist
  (a) comes forward as a net seller (buyer) at the second stage game;
  (b) brings along less (more) than his endowment to the second stage game;
  (c) has a final marginal abatement cost that is less (greater) than the equilibrium permit price. □

These results confirm intuition. Had a price taker brought anything else than his endowment to the second stage game, his final marginal abatement cost would differ from the permit price, which clearly is not optimal when that price is taken as given. A strategist, however, is more sophisticated. If he comes forward as a buyer, he wants to "push" prices down. He does so by bringing more than his endowment to the cooperative enterprise, thereby "flooding" that market. However, to finally make up for this excess supply, he must keep emissions below the number of permits aquired at the second stage. Thus his final marginal abatement cost will be higher than the equilibrium permit price. In contrast, a strategic seller wants to drive the price up. Whence he does not bring all his endowment to the second stage game, and similarly, he has a lower final marginal abatement cost than the equilibrium price.

It also appears that if one agent should have a large capacity of supplying or demanding permits at an "almost" constant marginal cost, r' would be close to zero, market power would practically be eliminated and an equilibrium in the neighborhood of the perfectly competitive outcome would be obtained. A regulator could take such a role by simply offering to sell or buy permits at a fixed price.[8]

[7] Proofs are relegated to Appendix II.

[8] The analogy of this result to cooperative risk sharing is clear: A risk neutral agent accepts all risks on behalf of others who thereby become fully insured.

3.2 Simulations

So, what predictions does this model give of the permit market under the Kyoto Protocol? Although all agents here may come forward as strategists, I shall—to allow for comparisons with the Hahn-Westskog model—compute how the permit price changes as the number of strategists increases from a perfectly competitive benchmark. Agents are included in the same order as in the previous section. Since in the alternative approach all agents take part in the cooperative market game, the model will henceforth be named the **full market model**.

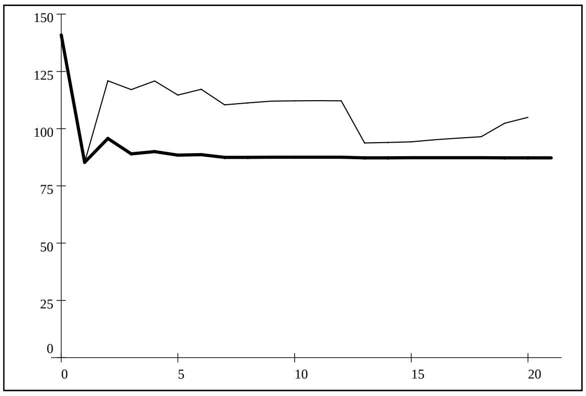

Figure 4. The permit price as the number strategists increases in both models. USD per ton carbon. [thick: full market model], [thin: Hahn–Westskog model].

First of all, we see from Figure 4 that the models predict the same equilibrium price in the case of perfect competition and when only the US manipulates the market. When Russia, a large supplier, is added to the strategic set, permit prices increase. However, this effect is more pronounced in the Hahn-Westskog model than in the full market model. In the latter, when more agents are modeled as strategists, prices are less dependent on the behavioral mode of each agent.

When it comes to the traded volumes, the differences between the two models are more pronounced.

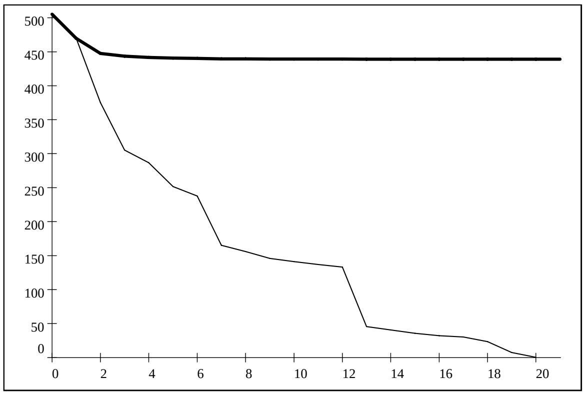

Figure 5. Total volume of permit traded as the number strategists increases. Million metric tons carbon per year. [thick: full market model], [thin: Hahn–Westskog model].

Figure 5 shows that in contrast to the Hahn-Westskog model, the full market one does not approach autarchy as more agents are modeled as strategists. It appears that the main reason for this is that the slope of the price curve in the alternative model, which enters the first order condition for the strategists, is less sensitive to how the set of price-takers is composed. In the full market model, after the US and Russia are assumed to make use of market power, the overall volume of the market is not much affected by the mode of behavior by the remaining agents.

The development of total costs across all parties, as the number of strategists increase, is given in Figure 6.

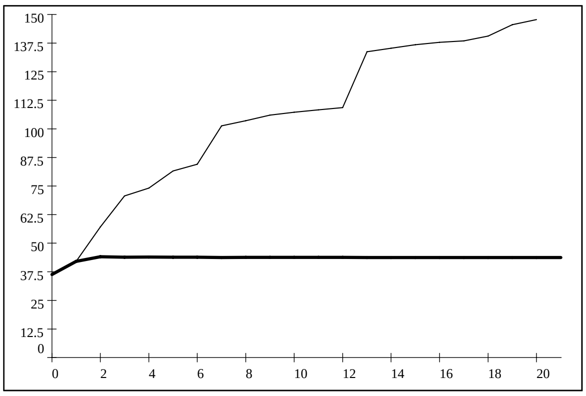

Figure 6. Total costs as the number strategists increases. Billion USD per year. [thick: full market model], [thin: Hahn–Westskog model].

Compared to the perfectly competitive equilibrium, total costs across all agents increase with about 20% when all are strategists in the full market model, giving a rather different picture than Hahn-Westskog model.

4 Some insights on the two approaches

From the simulations of the previous sections, it appears that the two models produce the same results when no strategic agent is present (i.e. perfect competition), as well as the case of monopoly or monopsony. This observation leads to

Proposition 2 (A comparison of the two models) *Suppose there is at most one strategic agent present, and that* $(\mathbf{z}_I, r)$ *is an equilibrium in the full market model. Then,* $(\mathbf{x}_I, p)$ *is an equilibrium in the Hahn-Westskog model if* $x_i = e_i - z_i + y_i$ *for each* $i \in I$ *and* $p = r$. $\square$

Moreover, the data behind Figures 4-6 motivates

Remark 1: *When more agents are modeled as strategists:*
(*i*) *The total volume of permits traded decreases in both models, and;*
(*ii*) *in the Hahn-Westskog model, this is at the expense of welfare.* $\square$

Remark 1 (*ii*) does not always apply in the full market model. Hence, it cannot be true generally there that more trade implies higher welfare (lower total aggregate costs). For instance, when the EU enters as the third strategist, the volume of the permit market is reduced as compared to when it takes the price for granted, yet total costs fall.

Some agent-specific results follow in

Remark 2: *When an agent is modeled as a strategist instead of being a price-taker, then, for given behavioral model of all other agents*
(*i*) *in both models, if that agent is a permit seller (buyer) as a price-taker, he remains a permit seller (buyer) when appearing as a strategist;*
(*ii*) *in the full market model, if he is a permit seller (buyer), prices increase (decrease) if making use of market power; and*
(*iii*) *in the full market model, he is better off by appearing as a strategist.* $\square$

Remark 2 (*i*) may appear obvious, but it is easy to construct an example, at least in the Hahn-Westskog model, when that is not the case. That is, an agent may come forward as, say, a permit seller if being a price-taker, yet he may appear as a permit buyer if making use of market power.[9] Moreover, Remark 2, parts (*ii*) and

[9] Here is one example: Say there are three agents in total. Each have the same marginal cost function, $c_i'(x_i) = -100 + x_i$ and endowments are $e_1 = 80$, $e_2 = 55$ and $e_3 = 40$. Then, if

(*iii*) do not hold in the Hahn-Westskog model. Regarding (*ii*), when Slovakia, a permit *seller*, appears as a strategist, prices *decrease*. To (*iii*), and with the exception of the "first" strategist (the US) it holds that for every agent added to the set of strategists thereafter, the agent is worse off by making use of market power.[10] If interpreting price-taking behavior as "infinite divisionalization" of one strategic entity, this result resembles that of Salant et al. [11] showing that aggregate profits for merging firms may be smaller than before merging.

5 Carbon trading without the US and Australia

Since the administrations of the US and Australia have indicated they will not ratify the Kyoto agreement, it may be relevant to simulate trade in their absence. The results are as follows.

Table 2. The Kyoto agreement without the US and Australia under various behavioral assumptions.

Model	Number of strategists	Permit price USD/tC	Volume traded MtC/yr	Total costs BUSD/yr
Both	0	-	388	-
Hahn-Westskog	4[1]	75.2	196	14.2
full market	4[1]	52.8	251	6.4
full market	19 (all)	50.0	245	6.7

[1] These are Russia, Ukraine, the EU and Japan.

Table 2 shows that the equilibrium permit price in the perfectly competitive case, vanish. This is because some agents, most notably Russia and Ukraine, have received so generous endowments that no emissions reductions are necessary for compliance.[11] In fact, their surplus of permits, more than covers the demand from other parties at a price equal to zero. This is similar to what is reported in the literature on the effect of the Kyoto agreement without US participation (see e.g. [13]).

Should Russia, Ukraine, the EU and Japan all make use of their market power, prices increase in both models, but more so in the Hahn-Westskog one. As in the case when the US and Australia were participating, the alternative approach implies more trade and lower aggregate costs.

agent 1 is a strategist, while agents 2 and 3 price takers, the equilibrium is given by $x_1 = 63.75$, $x_2 = x_3 = 55.625$, and $p = 44.375$ where $p' = 0.5$. Hence, agent 2 is a permit *buyer*. If agent 2 appears as a strategist, the equilibrium is given by $x_1 = 66.875$, $x_2 = 54.375$, $x_3 = 53.75$, and $p = 46.25$ where $p' = 1$. In this equilibrium, agent 2 is a permit *seller*.

[10] More transparently, this may be shown with the simple example of the previous footnote, should $e_1 = 80$, $e_2 = 50$ and $e_3 = 40$.

[11] This is due to the economic set-back over the last decade in these countries. A full (emissions) recovery is not expected before the Kyoto period of 2008-2012.

6 Concluding remark

This paper proposed a different model of trade in property rights when some—perhaps even all—could act strategically à la Cournot. The simulations using this model, suggested that it became of little importance whether relatively "small" agents made use of the market power they in principle possess. A feature not present in the traditional framework of Hahn and Westskog. Nevertheless, which model, if any, that produce reliable predictions is a matter for empirical, and perhaps experimental, research.

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Appendix I

The functional forms and parameters of the cost functions applied in the simulations were derived from simulation data provided by the International Institute of Applied Systems Analysis, Laxenburg, Austria. These data were extracted from the MERGE model developed by Manne and Richels [8] (see also www.stanford.edu/group/MERGE/). In essence, MERGE, (A **M**odel for **E**valuating the **R**egional and **G**lobal **E**ffects of Greenhouse Gas Reduction Policies) is an intertemporal computable general equilibrium model with a more detailed representation of the energy sector (the prime source of greenhouse gas emissions) than the remainder of the economy. Only the energy related CO_2-emissions were accounted for in the applied version of MERGE, which was calibrated to the so-called B2 emissions scenario made for the Intergovernmental Panel on Climate Change [10].

By imposing various levels of a global carbon tax in MERGE and computing the resulting emissions, marginal emissions cost functions were derived by simple OLS regression. They appeared to be approximated well by linear functions for taxes in the range 0 to 250 USD per ton carbon.

Holding a number of permits greater than what is needed without reducing emissions, obviously comes along without costs. Hence, cost functions are piecewise quadratic linear and given by

$$c_i(x_i) = \begin{cases} \frac{1}{2b_i}(b_i x_i - a_i)^2 & \text{when } x_i \leq a_i/b_i, \\ 0 & \text{when } x_i > a_i/b_i. \end{cases}$$

for all $i \in I$, where a_i, $b_i > 0$.

Not very satisfying for the purpose of this study, is the level of aggregation of countries in MERGE. For the relevant signatories of the Kyoto agreement, MERGE uses the aggregation 1) Eastern Europe and Former Soviet Union, 2) OECD Europe, 3) Canada, Australia and New Zealand, 4) Japan and 5) the US. By making use of the emissions in 1990 given on a country basis by the United Nations Framework Convention on Climate Change (http:\\unfccc.int), country-specific marginal cost functions were constructed on the basis of requiring that the emissions of a MERGE region would equal the sum of the emissions of the countries in that region, given any common marginal cost. The EU was assumed to come forward as a single entity covering the member countries prior to the May 1 2004 extension.

The endowments of permits in the Kyoto Protocol are defined as a percentage change of the emissions in the year 1990 for each party. To compute the endowments, the 1990 emissions level given by MERGE (so to obtain the same emissions coverage as for the cost functions) were combined with the required reductions percentages given in the Kyoto agreement. These MERGE-aggregate endowments where then disaggregated according to the national 1990 emissions levels. The parameters of the cost functions as well as the computed endowments are given in Table A1.

Table A1. The parameters used in the numerical analysis.

	Cost function parameters		Endowment
Units	Marg. costs measured in USD/tC		MtC/yr
Symbol	a_i	b_i	e_i
Australia	693	6.1	85
Canada	693	3.7	123
New Zealand	693	67.2	7
Bulgaria	1410	77.0	25
Czech Rep.	1410	39.1	51
Estonia	1410	171.0	11
Hungary	1410	90.4	22
Latvia	1410	261.0	7
Australia	1410	164.0	12
Poland	1410	17.0	116
Romania	1410	37.5	51
Russia	1410	2.7	768
Slovakia	1410	104.0	19
Slovenia	1410	465.0	4
Ukraine	1410	9.2	228
Japan	1730	4.9	258
Iceland	1880	2880.0	1
Norway	1880	176.0	10
Switzerland	1880	139.0	11
EU-15	1880	1.9	839
USA	1000	0.6	1250

APPENDIX II

Proof of Proposition 1. Assertion (i) follows immediately from the fact that at the second stage $r + c_i'(y_i) = 0$, while at the first stage $0 = r + c_i'(e_i - z_i + y_i)$ for all $i \in F$. Since c_i is strictly convex, it follows that $e_i - z_i = 0$. For (ii) I shall only consider a permit seller, since the case of a buyer then becomes obvious. I start with the assertion that (b) implies (c). Suppose on the contrary that $z_i < e_i$ implies $-c_i'(e_i - z_i + y_i) \geq r$. That furnishes the contradiction

$$0 \geq r + c_i'(e_i - z_i + y_i) = -c_i'(y_i) + c_i'(e_i - z_i + y_i) > 0$$

as $-c_i'(y_i) = r$, c_i is strictly convex (i.e. c_i' strictly increasing) and the assertion that $z_i < e_i$. The converse follows similarly. For (a) implies (b), suppose on the contrary that $z_i > y_i$ implies $z_i \geq e_i$. To contradict this implication, observe first that (8) and (9) implies that

$$0 < y_i'r' = \frac{1}{1 + \sum_{j \in I \setminus i} \frac{c_i''(y_i)}{c_j''(y_j)}} < 1. \tag{10}$$

Now, by making use of (7) I obtain the contradiction

$$\begin{aligned} 0 \quad &= (r + c_i'(e_i - z_i + y_i))(y_i'r' - 1) + r'(y_i - z_i) \\ &> (r + c_i'(e_i - z_i + y_i))(y_i'r' - 1) \\ &= (-c_i'(y_i) + c_i'(e_i - z_i + y_i))(y_i'r' - 1) \geq 0 \end{aligned}$$

as $r'(y_i - z_i) > 0$, $r = -c_i'(y_i)$, $z_i \geq e_i$, c_i' is increasing, and by (10), $(y_i'r' - 1) < 0$. Again, the converse is easily obtained. Thus, since (b) is equivalent to (c) and (a) is equivalent to (b) it follows that (a) is equivalent to (c). □

Proof of Proposition 2. What I need is that all the first order optimality conditions for the Hahn-Westskog model are satisfied for a given solution to the full market model. When there are no strategic agents, this follows immediately. In the case of monopoly (or monopsony), and by naming the strategic agent s, it follows from (8) that

$$r' = \left[-\sum_{i \in F} \left[c_i''(y_i) \right]^{-1} - \left[c_s''(y_s) \right]^{-1} \right]^{-1} = \left[-\frac{1}{p'} - \frac{1}{c_s''(y_s)} \right]^{-1}, \tag{11}$$

since for each $i \in F$, $x_i = e_i - z_i + y_i = 0 + y_i$ (Proposition 1 (i)). By combining (11) and (9) with a bit of algebra, I obtain

$$y_s'r' - 1 = \frac{r'}{p'}.$$

Thus, from (7) it follows for the strategist that

$$
\begin{aligned}
0 &= (r + c_s'(e_s - z_s + y_s))(y_s' r' - 1) + r'(y_s - z_s) \\
&= (p + c_s'(x_s))(\frac{r'}{p'}) + r'(x_s - e_s) \\
&= p + c_s'(x_s) + p'(x_s - e_s).
\end{aligned}
$$

The last equality is obtained by dividing throughout by (the non-zero) $\frac{r'}{p'}$. Again, it is easily verified that the first order optimaility conditions for those being price-takers also are satisfied. $\square$

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