Vol. 76 (2002), No. 2, pp. 101–122

Journal of Economics
Zeitschrift für Nationalökonomie
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Do Negotiated Agreements Lead to Cost Efficiency?

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Received October 16, 2000; revised version received August 2, 2001

In this paper, we model a negotiated agreement between the government and a polluting industry. The agreement states that the industry is obliged to reduce aggregate emissions, and in return, the government will not impose taxes on emissions. Our focus is on how the existence of such an agreement influences individual firms' incentives to reduce their emissions when the industry association has no direct control over its members. We show that although the threats of taxes may discipline the firms in the industry and lead to a reduction in emissions, these reductions in emissions are not cost efficient. More specifically, we show that large firms stand for a disproportionally large part of the reductions relative to small firms.

Keywords: environmental economics, emissions, negotiated agreements, cost efficiency.

JEL classification: I28.

1 Introduction

A core problem in environmental economics concerns externalities associated with harmful emissions. The standard policy recommendation from economists is to avoid direct regulations, but rather to tax emissions so that the negative externalities are internalised by the polluting firms. However, over the last two decades a new type of policy measure – referred to as *voluntary* or *negotiated* agreements between the government and firms or industries – has grown popular among policy makers. Supporters of negotiated agreements argue that this measure is superior both to taxes and direct regulations as it provides the flexibility of taxes without imposing any fiscal strains on the firms. Still, academic scholars have until recently shown little interest in voluntary or negotiated agreements.

The literature on voluntary and negotiated agreements has so far been dominated by policy-oriented contributions, see e.g., Wallace (1995), and some of the core terms in this literature are not precisely defined. What is a voluntary agreement? Often, at least in Europe, "voluntary agreements" are extensively bargained over before they are signed, and an agreement is often backed by a threat by the government to introduce environmental taxes if the agreement is not honored by the industry. For European-style agreements, the term negotiated agreements may therefore be more appropriate than voluntary agreements. As our focus is on European-style agreements, we will use this term.

The arguments in favor of (negotiated) agreements may also be diffuse. For instance, proponents have claimed that agreements will stimulate a "pro-active" attitude to environmental problems from the industry. What precisely is a pro-active attitude? Does it lead to cost-efficient reduction? Our contribution is to show how a negotiated agreement can be defined within the framework of economic models. More specifically, we argue that it is appropriate to model the co-ordination game between the firms in an industry which has signed an agreement as a co-ordination game. As a result, we can undertake a welfare analysis, and examine whether, or under what conditions, negotiated agreements lead to cost-efficient reductions in emissions.

It is natural to distinguish between two different kinds of negotiated agreements; firm-specific agreements and industry-wide agreements. Firm-specific agreements, in which the government signs an agreement on emissions from one specific firm, have a strong resemblance to direct regulations and may be regarded as an (agreed upon) environmental standard. However, in contrast to direct regulations, an agreement must be approved by the firm as well as by the government. It is therefore hard to see what the government can obtain through negotiated agreements on the firm level that it could not have obtained through direct regulation of the firm in question. Therefore, in this paper we focus on industry-wide negotiated agreements. In most industry-wide agreements, the industry is supposed to reduce total emissions. Yet, the agreements do not dictate (at least not fully) how the reductions in emissions should be distributed among the firms in the industry. Furthermore, as industry organisations have limited possibilities to dictate the behavior of their members, it is to a large extent up to the individual firm to decide how it will react to the agreement.

With agreements firms cover the abatement costs but do not pay for the remaining emissions. Since emissions are socially costly, textbook economics implies that with agreements the investment decisions of firms will in general not be socially optimal.[1] The best one can hope for is that negotiated agreements are cost efficient in the short run (like optimally set environmental standards), in the sense that the emissions at any point in time are allocated efficiently on firms (given the number of firms and their technologies). Whether negotiated agreements are cost efficient in the short run is the major issue addressed in this paper.

More specifically, we consider negotiated agreements on the industry level, stating that the aggregate emissions from the industry should fall below a given target. In return, the government will not impose taxes unless the agreement is violated by the industry. We analyse the coordination problem that arises between the firms in the industry in order to reach the aggregate target. To this end, we use a model similar to the model in Holmstrom (1982) and in Green and Porter (1984). An important finding is that when negotiated agreements are supported by taxes (i.e., taxes will be introduced if the agreement is violated), the agreement does not lead to cost efficiency, as large firms stand for a disproportionately large part of the reductions in emissions. Our simulations suggest that these inefficiencies could be substantial.

As mentioned above, the economics profession has not devoted much interest in agreements as a policy instrument. Still, there are some papers discussing the concept of "voluntary agreement" and provide assessments of the experience with voluntary and negotiated agreements, see e.g., Hansen (1996) and Sunnevåg (1997). Furthermore, Nyborg (2000), Amacher and Malik (1998), and Segerson and Miceli (1998) examine agreements between the government and individual firms. However, to our knowledge there is no paper on the effects of industry-wide negotiated agreements on the behavior of individual firms.[2]

The rest of the paper is organised as follows: in Sect. 2, we give a short overview of negotiated agreements in various countries, and use this to

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1 Note the parallel with environmental standards, which in a static setting may give rise to the same allocation of emissions as an (optimally set) environmental tax. Still environmental standards are not efficient in a dynamic setting when investments and/or entry and exit decisions by firms are included in the analysis. With environmental standards we typically get too little exit (and too much entry) since the firms then do not have to pay for the rest-emissions and thus obtain a too high profit.

2 Nyborg (2000) discusses industry-wide agreements, but disregards the coordination problems between firms that are addressed in the present paper.

rationalize our modelling approach. The model is presented in Sect. 3. We use an infinitely repeated game to analyze industry-wide negotiated agreements. In Sect. 4, we analyze the welfare properties of the equilibrium supported by taxes. We show that the equilibrium is not efficient, and illustrate the magnitude of the inefficiencies by simulations. The time consistency of the government's policy is discussed in Sect. 5. The final section gives policy recommendations and concludes.

2 Formalizing Negotiated Agreements

In this section, we first describe a sample of existing negotiated agreements. Then we discuss the main principles behind our model before we present it in detail.

2.1 Negotiated Agreements

In Europe, negotiated agreements are most frequently used in the Netherlands. The Dutch programs cover, among other things, waste management, emission of harmful gases (VOC, SO_2, NO_x, CO_2), noise from manufacturing firms and energy efficiency, see Sunnevåg (1997). Typically, national and local authorities meet with representatives of an industry in order to set environmental targets for a future year, e.g., 2010. While the agreements do not cover sanctions, in the last generation of agreements the parties are free to sue each other if they feel that the other party has violated the agreement. Negotiated agreements are also frequently used in Germany. As in the Netherlands, most of the agreements are on the industry level. There are presently more than sixty German agreements in place, covering emissions to water, emissions of greenhouse gases, toxic waste and garbage.

In the Scandinavian countries, several agreements have lately been reached between the government and representatives of industries. One example is the agreement with the Norwegian aluminium industry to cut (sectoral) emissions of greenhouse gases by 55 percent by the end of 2005. In return, the government has announced that it will not tax the emissions, see Misvær (1999). Moreover, several negotiated agreements on reduction and recycling of packaging waste have been signed by the Norwegian Ministry of the Environment and representatives of an industry organization. According to the government, a tax on packaging materials may be imposed if the stipulated targets (collecting and recycling 60 to 80 percent of several broad categories of packaging materials) are not reached, see Nyborg (2000). It is not clear to what extent the agreements in Scandinavia are legally binding, but the main factor motivating the industry to honor the agreements seems to be a threat from the government to punish repudiation by introducing costly policy measures such as taxes.

The examples above suggest that there is a collective aspect of most industry-wide negotiated agreements. In Europe, industry associations (e.g., employer associations) play an important role in the negotiations with the government on the terms of the agreement. Often, industry associations also act as signatories.

2.2 Modelling Negotiated Agreements

From an economic perspective, industry-wide agreements raise a number of important questions: do industry-wide agreements give individual firms incentives to reduce their emissions? Can such agreements be sufficient in order to reach ambitious environmental targets and, if so, will the reductions in emissions be cost efficient?

In order to answer these questions, we construct a model in which the government reaches an agreement with an industry association on reductions in emissions. Although industry associations may play an important role in the bargaining process with the government, these associations seldom have the power to fully determine the behavior of their members. To make our points sharp and the analysis tractable, we assume that the industry association has no sanctions to use against firms that do not comply with the agreements. Our assumption on this point may be less restrictive than one may first think. Even if the industry association had some control over emissions from individual firms, it would be natural to think of the association's decisions as the outcome of a negotiation game between the firms in the industry. One such negotiation game is the Nash demand game (Nash, 1953), which Nash used to rationalize his famous Nash bargaining solution. The Nash demand game would give a similar equilibrium outcome as our full-response equilibrium derived below, provided that side-payments are excluded.[3]

3 In a previous version of this paper we have shown that results analogous to the results obtained here can be derived by directly using the Nash bargaining solution. However, in addition to some technical difficulties, a Nash bargaining approach makes it difficult to interpret, and give intuition to, the obtained results. We therefore decided to use a non-cooperative model.

In order to focus solely on the effects of the collective penalty, we assume that no additional agreements between individual firms and the government are signed. This is an innocent assumption, as our focus is on the flexibility created by having targets on the industry level.

Finally, as mentioned above, negotiated agreements are often accepted after the parties have bargained extensively over the aggregate emission level. We do not model this bargaining game, but focus on the effects of a given agreement. This does not mean that we believe the bargaining rounds are unimportant, but rather that the effects of a given agreement, for a given emission target, can be analyzed independently of how the bargaining was performed. Furthermore, this means that our model is also appropriate for more loosely defined agreements, where the government simply signals to the industry that policy measures will be introduced unless the aggregate emissions are found "acceptable".

2.3 The Model

We consider an industry with a given number of firms, which as a by-product to the production process discharge pollutants which damage the environment. The model is set in discrete time with infinite time horizon.

In order to focus on the issue of emissions, we assume that all markets are competitive so that the emission of pollutants is the only source of externalities in the economy. We summarize the production technology in firm i by a concave (pre-tax) *profit function* $\pi_i(x_i)$, showing the per-period profit of firm i as a function of its emissions in that period, x_i (for notational simplicity, we omit the time index).[4] Let $x_i^0 = \arg\max_{x_i} \pi_i(x_i)$, that is, the (per-period) emission level that maximizes firm i's profit with no constraint on emissions. In an unregulated economy, it follows that $x_i = x_i^0$ for all i. For all $x_i < x_i^0$, we have $\pi_i'(x_i) > 0$ and $\pi_i''(x_i) < 0$,

4 This profit function summarizes a firm's technology in a general way. To see this, suppose the per-period production function of the firm can be written as $y_i(z_i)$, where $z_i = (z_i^1, \ldots, z_i^k)$ is, a vector of inputs. We assume that $y_i(z_i)$ is strictly concave in z_i. Let the emission from firm i, x_i, be written as $x_i = e_i(z_i)$, where some of the inputs in z_i can be used to reduce the level of emission (cleaning). We assume that e_i is convex in z_i. We also assume that the price of output is constant and normalized to one, while the price vector of inputs is also constant and given by q. The profit function $\pi_i(x_i)$ is then defined as $\pi_i(x_i) = \max_{z_i} y_i(z_i) - qz_i$ S.T. $e_i(z_i) \leq x_i$. Since y_i is strictly concave and e_i is convex in $(z_1, \ldots, z_n)$, it follows that $\pi_i''(x_i) < 0$.

reflecting that it is costly to reduce emissions and that the marginal cost of a *reduction* in emission is decreasing in the initial emissions' level (i.e., the cleaning cost is convex).

As discussed in the previous subsection, we assume that the agreement contains no clauses regarding emissions from individual firms. Thus, the firms face a co-ordination problem, in the sense that they have a collective interest in reducing their aggregate emission level below the target, while individual firms have an incentive to free-ride on the other firms. In order to solve such a co-ordination problem, it is a well-known fact that one cannot make the simplifying assumption that the agents have full information, as this would eliminate the predictive power of the model. To see this, consider the emissions in one period, and suppose all firms have full information about the aggregate emission target $\bar{X}$. Then each firm has incentives to set the level exactly equal to the difference between the target and the sum of the opponents' aggregate emissions. Thus, any vector $(x_1, \ldots, x_n)$, $x_i \leq x_i^0$ which sums to $\bar{X}$ constitutes an equilibrium, provided that the pay-off $\pi_i(x_i)$ to any firm i is higher than the pay-off it obtains if a tax is introduced.

We therefore follow Nash (1953), and Holmström (1982), and assume that there is some uncertainty regarding how large the emissions can be before the government reacts. We interpret this uncertainty as measurement errors in observed aggregate emissions.[5] We then study the equilibrium in the limit as the uncertainty vanishes. More specifically, we assume that the observed aggregate emissions, $\hat{X}$, can be written as

$$\hat{X} = X + \sigma Z ,$$

where X is actual aggregate emissions, Z is a stochastic variable with variance normalized to one and expectation equal to zero, and σ is a scaling parameter showing the variance of the noise term. Moreover, we assume that the distribution of Z is unimodal with finite support $[z^{\min}, z^{\max}]$. We assume that Z is independently drawn in each period, and we denote the cumulative distribution function of Z by $F(z)$ and the associated density by $f(z)$.

5 As mentioned above, there may also be other reasons for this uncertainty than measurement errors, for instance that the target is not defined precisely. This is especially relevant if the target reflects what the government thinks is "reasonable".

For a given aggregate emission level, the probability that the measured emissions are above the target, and thus that the government reacts, is given by

$$P(X) = Pr\left[\hat{X} \geq \bar{X}\right] = Pr\left[Z \geq \frac{\bar{X} - X}{\sigma}\right]$$
$$= 1 - F\left(\frac{\bar{X} - X}{\sigma}\right) . \tag{1}$$

If the aggregate emission target is not met, we assume that the government introduces environmental taxes. The length of the punishment period may be a decision variable for the government. This will be discussed in some detail below. At this stage we just assume that the taxes will be introduced for one period only, and that a new agreement will be implemented thereafter. Let t denote the tax rate that is implemented. We assume that the tax rate is set so that the aggregate emission level X equals the target $\bar{X}$.

The co-ordination game is assumed to proceed as follows:

(i) In the beginning of each period, the government announces whether an agreement with target $\bar{X}$ (the same in each period) or taxes will be used in that period. In the first period, the announced policy measure is an agreement.
(ii) All firms then simultaneously and independently choose emission levels.
(iii) If the policy measure is an agreement, the probability that taxes will be implemented in the next period is $P(X)$ (with $X = \sum_{i=1}^{n} x_i$).
(iv) If the policy measure is taxes, the firms know with certainty that an agreement will be implemented in the next period.

In what follows, we first take the government's behavior as exogenously given. In Sect. 5, we endogenize this behavior by deriving it as an equilibrium strategy of the government.

3 Equilibrium

We know from the folk-theorems that a repeated game like that described in the previous section has infinitely many solutions. As is standard in the literature we restrict the strategy space to include Markov strategies only. We thus assume that the emission level of a given firm depends on the policy measure that is used in that period only, that is, "the state of the world", and not on the history of the game. Let S denote the state of the world, and let $S = a$ if the policy measure is an agreement and $S = t$ if it is taxes. Let x_i^a and x_i^t denote the emission levels from firm i when $S = a$ and $S = t$, respectively. Furthermore, let Π_i^a and Π_i^t denote the (equilibrium) present discounted income when $S = a$ and $S = t$, respectively. Finally, let $\delta < 1$ denote the discount factor. If $S = a$, firm i will choose x_i^a so as to solve the problem

$$\max_{x_i^a} \pi_i(x_i^a) + \delta[P(X)\Pi_i^t + (1 - P(X))\Pi_i^a] \qquad (2)$$

given that $X = \sum_{i=1}^n x_i^a$. By definition, Π_i^a is equal to this maximum. If $S = t$, firm i solves the problem

$$\max_{x_i^t} \pi_i(x_i^t) - tx_i^t + \delta\Pi_i^a \ , \qquad (3)$$

that is, $\pi_i'(x_i^t) = t$ for all i. A solution of the co-ordination game is referred to as a (Markov) equilibrium:

Definition: A *Markov equilibrium* (or just equilibrium) of the model consists of two vectors $(x_1^a, \ldots, x_n^a)$ and $(x_1^t, \ldots, x_n^t)$ that solve (2) and (3), respectively, for each i, given the actions of the other firms.

Our focus is on how firms behave under agreements. Consider an arbitrary firm i. By taking derivatives of (2) (assuming an interior solution) we obtain the first-order condition:

$$\frac{\pi_i'(x_i^a)}{\Pi_i^a - \Pi_i^t} = \delta P'(X) \ . \qquad (4)$$

All firms face a trade-off between costly cleaning in this period and a higher probability of taxes being imposed in the next period, and choose an emission level so as to optimally balance these costs. We define the *full-response equilibrium* as an equilibrium in which all firms' emissions are given by (4) when the policy measure is a negotiated agreement, and by x_i^t when the policy measure is taxes. We assume that taxes are a sufficiently bad alternative in the sense that the gain $\pi_i(x_i^0) - \pi_i(x_i^a)$ by deviating from x_i^a and setting the emissions equal to x_i^0 is less than the discounted cost following from one period with taxes, $\delta[\pi_i(x_i^a) - (\pi_i(x_i^t) - tx_i^t)]$.[6] Then we can show the following proposition:

Proposition 1: For sufficiently low values of σ and high values of δ, there exists a full-response equilibrium. Furthermore, in the limit as $\sigma \to 0$, the following holds (when the policy measure is agreement):

(1) Aggregate emissions X converge to the target $\bar{X}$.
(2) The probability that the target will be met converges to one (P converges to zero).

The proof is given in the Appendix. It follows that in the limit, as $\sigma \to 0$, the full-response allocation is given by:[7]

$$\begin{aligned} \frac{\pi_i'(x_i)}{\Pi_i^a - \Pi_i^t} &= C \quad \text{for all } i \ , \\ \sum_{i=1}^n x_i &= \bar{X} \ . \end{aligned} \tag{5}$$

From (2) and (3) we know that $\Pi_i^t = \pi_i(x_i^t) - tx_i^t + \delta\Pi_i^a$ and $\Pi_i^a = \pi_i(x_i^a) + \delta\Pi_i^a$ when $\sigma \to 0$ (since $P \to 0$). Inserted into (5) this gives

$$\frac{\pi_i'(x_i^a)}{\pi_i(x_i^a) - \pi_i(x_i^t) + tx_i^t} = C \ . \tag{6}$$

Together with the requirement that aggregate emissions are equal to the target $\bar{X}$, this equation determines $(x_1^a, \ldots, x_n^a)$. As the nominator in (6) is

6 If this is not satisfied, the government must punish the firms with taxes for more than one period if the target is not met. The hardest punishment the government can impose on the industry is to switch permanently to taxes. In this case we can show that for sufficiently low values of δ, an agreement exists as long as all firms, in a given period, prefer an agreement to taxes; that is, $\pi_i(x_i^a) > \pi_i(x_i^t) - tx_i^t$.

7 In Golombek and Moen (1999), we analyze the equilibrium of the model without letting the noise term vanish. We show that as long as σ lies within a certain range, the full-response equilibrium still exists. Furthermore, our cost-inefficiency results derived below still hold as well. However, when σ is finite there is a positive probability that the target is not met and that taxes are introduced.

decreasing in x_i^a while the denominator is increasing in x_i^a, it follows that the full-response equilibrium is unique as $\sigma \to 0$.

Below, when we analyze the full-response equilibrium, we focus solely on the limit case where $\sigma \to 0$. Note that in this equilibrium taxes will never be introduced as the target is reached with probability one.

However, it is worth noting that the full-response equilibrium is not the only equilibrium in this model. To see this, suppose all firms j but firm i choose not to respond to the agreement and choose the quantity x_j^0 that maximizes $\pi_j(x_j)$, $j \neq i$. Consider firm i. For sufficiently low values of σ it follows that $P = 1$ independently of x_i. Firm i's profit is thus (from (2)) $\pi_i(x_i) + \delta\Pi_i^t$, which is maximized $x_i = x_i^0$.

Lemma 1: For sufficiently low values of σ, there also exists a no-response equilibrium in which emissions from firm i are given by x_i^0 for all i, provided that the policy measure in that period is agreement.

It is easy to show that the full-response equilibrium Pareto dominates the no-response equilibrium in the sense that all firms obtain a higher expected profit in the full-response equilibrium than in the no-response equilibrium.[8]

4 Cost Efficiency of the Full-Response Equilibrium

In this section, we analyze whether negotiated agreements yield a cost-efficient allocation of emissions on firms. We focus on the most "optimistic" of the possible equilibria, the full-response equilibrium.

A cost-efficient allocation of emissions is an allocation where the target is satisfied and all firms have the same marginal abatement cost, that is, $\pi_i'(x_i) = \pi_j'(x_j)$ for all i, j. With taxes, $\pi_i'(x_i^t) = t$ for all i, and as the tax rate by assumption is set so that $\sum_{i=1}^{n} x_i = \bar{X}$, it follows that the allocation of emissions with taxes is cost efficient. Furthermore, from (6) it follows directly that in the full-response equilibrium the allocation of emissions will be cost efficient if all firms are equal, since the maximization problem will then be the same for all firms. However, this is not

8 In addition to the no-response and the full-response equilibria, there may also be other equilibria where some firms respond and other firms do not respond to the agreement. However, below we examine only the full-response equilibrium.

very interesting, as it is when firms are heterogeneous, that cost efficiency may be difficult to obtain.

Our focus is on firm size as the only source of heterogeneities. We first look at a case where the firms in the industry are of two types, large and small. Then we study a special case where all production in the economy takes place in identical plants. We also construct a numerical example in order to illustrate the magnitude of the inefficiencies of the full-response equilibrium compared with the first-best solution.

4.1 Two Types of Firms

In order to define a (partial) ordering of firm size we use the profit function π. For any firm i, define $x_i(s)$ as the solution to the equation $\pi_i'(x_i) = s$. Thus, $x_i(s)$ shows that value of x_i where the marginal cost of emissions is equal to s. Put differently, x_i shows the optimal emission level of firm i as a function of the tax level $t = s$. We now define firm size as a partial ordering, in the following way:

Definition 1: A firm i is larger than firm j if $x_i(s) > x_j(s)$ for all $s \geq 0$.

Thus, a firm is larger than another firm if, for any tax level, the optimal emission level is higher for the larger firm than for the smaller firm. Put differently, if a large firm and a small firm have the same marginal abatement costs, the emissions from the larger firm are higher than the emissions from the smaller firm. Suppose the industry consists of two types of firms, large firms and small firms. Our next proposition tells us that with negotiated agreements, the abatement costs for large firms will be higher than for small firms:

Proposition 2: Suppose the industry consists of large and small firms as described above. Then the full-response equilibrium is not cost-efficient as the large firms have higher marginal abatement costs than the small firms in equilibrium.

Proof: Let i denote a large firm and j a small firm. We have to show that the marginal abatement costs are higher in firm i than in firm j. Suppose this does not hold, that is, suppose $\pi_i'(x_i^a) \leq \pi_j'(x_j^a)$. From Eq. (6) it then follows that

$$\Pi_i^a - \Pi_i^t \leq \Pi_j^a - \Pi_j^t \ . \tag{7}$$

That is, the loss if taxes are introduced is at least as large for the small firm as for the large firm. Suppose first that the marginal abatement costs are the same in the two firms in the full response equilibrium, as it is with taxes. Since aggregate emissions are the same with taxes and with agreement, it follows that the emissions for both types of firms must be the same with taxes as in the full-response equilibrium. However, then it follows that $\Pi_i^a - \Pi_i^t = tx_i(t)$ and that $\Pi_j^a - \Pi_j^t = tx_j(t)$. However, since by definition $tx_i(t) > tx_j(t)$, Eq. (7) cannot be satisfied. Therefore, the loss if a tax is introduced is larger for the large firms than for the small firms.

Suppose then that the marginal abatement costs are higher in the small firm than in the large firm. It follows that $x_i^a > x_i^t$ and $x_j^a < x_j^t$ (since aggregate emissions are the same with and without taxes). However, this increases $\Pi_i^a - \Pi_i^t$ and decreases $\Pi_j^a - \Pi_j^t$ relative to the situation above with equal marginal abatement costs. But then (7) cannot be satisfied, and we have again derived a contradiction. □

To get the intuition for this result, we must consider the situation where σ is small but not infinitesimally small. First note that there is a fundamental difference between how taxes work when supporting an agreement and when used directly. Used directly, the marginal cost of emission for a firm is equal to the tax rate, and thus the same for all firms, independent of firm size. On the other hand, when taxes are used to support an agreement, the marginal cost of emissions is due to an increased probability of policy measures being introduced. Obviously, this cost depends on total (not marginal) tax payments and thus is higher in a large than in a small firm. As a result, large firms reduce their emissions more than small firms do.

Put differently, taxes work as a collective penalty because they are imposed if the agreement is not met. More emissions from one firm create a negative externality for the other firms as this increases the probability that taxes are introduced. Thus, the situation is similar to the well-known common-pool problem, and it follows that the marginal costs of own emissions (resulting from an increase in the probability that taxes are introduced) is greater for a large firm, than for a small firm simply because the tax base is larger.

What if the size of the firms in the industry takes more than two different values? In this economy, consider a firm i' that has the same emission level when there is a tax as it has when there is an agreement, and thus has a marginal abatement cost equal to t in the full-response equilibrium. Then it is straightforward to show that all firms larger than i' have abatement costs that exceed t in the full-response equilibrium, while all firms smaller than i' have abatement costs smaller than t in the full-response equilibrium.[9]

4.2 A Special Case: Identical Plants

In this section, we study a special case where production in the economy takes place in identical plants. A firm's size is then equal to the total number of plants it possesses. Let the production technology of a single plant be summarized by a profit function $\pi(x)$, where x denotes emissions from this plant. As the profit function is assumed to be concave in x, a firm that owns several plants will allocate a given total level of emissions evenly on the plants. If firm i is in possession of k_i plants, its total profit is $\pi_i(x_i) = k_i\pi(x_i/k_i) = k_i\pi(x_i^e)$, where x_i^e denotes emissions per plant in firm i. It follows that $\pi_i'(x_i) = \pi'(x_i^e)$. Obviously, efficiency requires that $\pi'(x_i^e)$ is the same for all firms, and, therefore, that the emissions per plant, x_i^e, are the same for all firms. Let $x^{e^*} = \bar{X} \,/\, \sum_{i=1}^n k_i$ denote this emission level. With taxes we know that the emissions from each plant are given by x^{e^*}. Inserting this and the expressions for π_i and π_i' into (6) gives

$$\frac{\pi'(x_i^e)}{\pi(x_i^e) - \pi(x^{e^*}) + tx^{e^*}} = k_i C \ . \tag{8}$$

Since the left-hand side is decreasing in x_i^e, emissions per plant are falling in k_i. Thus, firms with many plants have lower emissions per unit than firms with fewer plants:

Proposition 3: The full-response equilibrium is not cost efficient. Furthermore, a firm's marginal abatement costs are strictly increasing in the firm's size.

9 It is also possible to achieve sharper results than this if we put more restrictions on $x(s)$. Suppose that (i) $|x'(s)|$ is greater in a large firm than in a small firm for all s, and (ii) if firm i is larger than firm j, then $x_i(s)/x_j(s)$ is falling in s. This is sufficient (but in no way necessary) to ensure that the abatement costs are strictly increasing in firm size.

Note that the gain from increased emissions in terms of lower cleaning costs is private to the firm in question. By contrast, all firms in the industry lose if taxes are introduced. Therefore, there is a negative externality on other firms from polluting. The larger the firm, the larger will be the share of the total costs borne by the firm and the higher will be the firm's willingness to reduce emissions. For instance, if two plants are organized as separate firms, the manager in each of them will only take into account the costs of his own plant when evaluating the effects of taxes. If the plants have common ownership, the manager will internalize the compliance costs of the second plant and will therefore be more willing to reduce emissions.

4.3 A Numerical Illustration

The inefficiencies associated with a negotiated agreement supported by taxes may be substantial. In order to illustrate the magnitude of this inefficiency, we have solved the limit full-response equilibrium numerically under the assumption that the profit function of an individual plant can be written as $\pi(x^e) = A - (x^0 - x^e)^2$, where x^0 is the emission level per plant without any environmental policy and A is the associated profit.[10]

In the simulations we have assumed that there are two types of firms; type 1 firms have only one plant ("small firms"), whereas type 2 firms have more than one plant ("large firms"). Moreover, we have assumed that for each type of firms, the total number of plants is 20. Thus, there are 20 small firms, while the number of large firms depends on their size. The first table shows the ratio of marginal abatement costs of large firms relative to small firms. When aggregate emissions are reduced by 10 percent, this ratio equals 1.9 when there are 10 large firms (each operating 2 plants), and increases to 16.3 when there is only 1 large firm (operating 20 plants). When the aggregate emissions are reduced by 50 percent, the corresponding numbers are 1.4 and 3.7. More generally, the marginal cost ratio increases as the number of large firms increases, whereas the marginal cost ratio falls as the magnitude of the emission reduction increases (and reaches 1 as all emissions are eliminated).

10 This profit function can be regarded as a second-order Taylor approximation of the true profit function, evaluated at $x^e = x^0$. Note also that we do not need to specify the discount factor, as this does not influence the equilibrium allocation of emissions, see Eq. (5).

As a measure of the welfare loss associated with negotiated agreements, we calculate the excessive cost of reducing emissions using agreements relative to the costs when the cost-efficient allocation is implemented. Aggregate costs are measured by the drop in aggregate profits in the industry.[11] Table 2 shows the results for different numbers of large firms and for different magnitudes of aggregate reductions in emissions. With 10 large firms (each operating 2 plants), the excessive costs are 9 percent when the reduction in aggregate emissions is 10 percent and fall to 3 percent when the reduction is 50 percent. When there is only one large firm, the corresponding numbers are 78 percent and 33 percent.

Table 1. Marginal abatement costs of large firms (type 2 firms) relative to marginal abatement costs of small firms (type 1 firms)

Number of large firms	Reduction in aggregate emissions, percent		
	10	25	50
10	1.9	1.7	1.4
5	3.5	2.9	2.0
2	8.3	5.9	2.9
1	16.3	10.5	3.7

Table 2. Excessive costs of using agreements relative to the cost efficient solution

Number of large firms	Reduction in aggregate emissions, percent		
	10	25	50
10	9	7	3
5	31	23	11
2	62	50	24
1	78	68	33

5 Endogenizing the Government's Policy Rule

An important issue is whether the behavior that we have assumed the government follows, cf. Sect. 2, can be derived as an equilibrium strategy.

11 It follows that the excessive cost ratio is given by $[(\sum_{i=1}^{n} k_i[\pi(x^{e0}) - \pi(x_i^e)])/\ (\sum_{i=1}^{n} k_i[\pi(x^{e0}) - \pi(x^{e^*})])] - 1$ where x^{e0} is the emission level that maximizes plant profit π, and x_i^e is the (per plant) full-response emission level of firm i (given by (8)).

In order to address this question, we first have to specify the government's preferences. We assume that the government, for instance due to political-economy reasons, *cet. par.* prefers an agreement where the firms play the full-response equilibrium in a system where taxes are used directly; if not, there is no reason to introduce agreements in the first place. Secondly, we assume that the government prefers taxes to an agreement if the agents play the no-response equilibrium.

Now consider the following strategy which is equivalent with the behavior postulated for the government in Sect. 2:

(1) In the first period, the government chooses the agreement strategy.
(2) In later periods:
  (a) If the policy measure in the previous period was agreement and the target was not reached, the government choose taxes.
  (b) Otherwise, the government chooses the agreement strategy.

When the government is introduced as a player, the strategy space for the firms becomes larger. We propose the following strategy for the firms:

(1) Start by playing according to the full-response strategy (that is, play x_i^a in periods where the policy measure is agreement and play x_i^t when it is taxes, for all i).
(2) If the government plays agreement although the policy measure in the previous period was agreement and the target was not met, play the no-response strategy (that is, play x_i^0 for all i).

Thus, loosely speaking, if the government does not punish a violation of an agreement in one period, the firms do not believe the government will do so in the next period either. Since both the full-response and the no-response equilibrium are sub-game perfect, this strategy is a best-response strategy for all firms given the strategy of the other firms and of the government.

It is easy to show that the proposed strategy for the government is a best-response strategy at all stages of the game. In order to do this we apply the one-stage-deviation principle (Fudenberg and Tirole, 1991, pp. 108–110). If the policy measure in the previous section was taxes, it is optimal for the government to play agreement in the next period as long as the firms play full-response, since the government prefers agreement to taxes (given that the target is met). The same holds if the government played agreements in the previous period and the target was met. Finally, consider the situation where the policy measure is agreements and the target was not reached in the previous period. If the government deviates and chooses agreement, the firms play according to the no-response strategy. Thus, it is better for the government to play taxes. Thus, we have shown the following proposition:

Proposition 4: Suppose the government's preferences are as described in the text. Then, if the discount factor is sufficiently close to one, the strategies defined above form a sub-game perfect equilibrium.

6 Concluding Remarks

We have studied a situation where the government introduces a negotiated agreement, stating that aggregate emissions in the industry are supposed to reach a pre-specified target. Otherwise, the government will introduce environmental taxes in the industry. We have shown that under reasonable assumptions there exists an equilibrium in which all firms reduce their emissions as a response to this threat. Yet, even if the emission target is met, this does not necessarily lead to an efficient allocation of emissions on firms; if firms differ substantially in size, there may be severe inefficiencies as the large firms will take a disproportionately large share of the abatement costs.[12,13] We have also shown that the model may have other equilibria than the full-response equilibrium, such as the no-response equilibrium which leads to even worse results from the government's point of view.

Are our results consistent with empirical findings? Since most of the negotiated programs that have been implemented are new, evaluations are relatively scarce. However, the experience so far seems to be consistent with our findings that multiple equilibria may prevail. Negotiated agreements on energy efficiency in the Netherlands that ran to year 2000 were on

12 There may also be severe inefficiencies if the noise parameter σ is finite.

13 The observation that the features of the supporting economic measure (taxes) differ from the features of the agreement (standard environmental taxes provide cost efficiency, whereas the "derived" instrument does not) resembles the well-known result from the finance literature that a stock (the primary asset) may have different features than an option based on this stock (the derived asset).

schedule. On the other hand, an agreement between the Finnish industry and the government in 1992 on energy consumption had a very limited effect, and the same is true for a Swedish agreement on recycling. Ytterhus (1997) finds that "environmentally active" firms are, on average, far larger than firms that are not. This finding seems to support our result that small firms may have a tendency to free-ride on large firms in response to an agreement.

Because our model has many equilibria, some of which may lead to reduced emissions and some not, the government may wish to initiate and participate in communication between the firms in the industry in order to reach the "right" equilibrium. Furthermore, to improve efficiency the government may allow the firms to pay each other side-payments. If we introduce side-payments between firms, it seems reasonable that firms could use this measure to exploit the differences in abatement costs that prevail in the full-response equilibrium. In line with the Coase theorem we would thus expect a cost-efficient allocation of emissions.[14] Note, however, that this may be a dangerous strategy as it may induce co-operation on other issues as well, such as forming a cartel.

Our results suggest that environmental taxes are superior to negotiated agreements when the agreements are supported by the same taxes. However, this result depends on our assumption that taxes can be imposed on emissions directly, without any administrative costs. In many circumstances this is not realistic. Firstly, there may be large costs associated with measuring firm-specific emissions. Secondly, the measurements may be inaccurate and therefore unsuitable as a tax base. Often, therefore, the only alternative for the government is to tax inputs and/or outputs that are only imperfectly correlated with the emissions.[15] However, it is well known that this leads to distortions, as the firms' primary interests will be to reduce the tax base rather than the emissions themselves.

Although it may be impossible, or prohibitively costly, for the government to measure emissions from individual firms, it may be relatively easy for the government to obtain a sufficiently accurate estimate of

14 This prediction is confirmed in Golombek and Moen (1999), Sect. 7.1.

15 To take one example, it is very costly to measure the emissions of dioxins from incinerators. Instead, one can measure the amount of chlorinated organic material (for example, PVC and PCB) in the feed, which is correlated (but not perfectly correlated) with the content of dioxins in the flue gas.

aggregate emissions. For instance, if firms discharge pollutants into a river, the government may estimate aggregate emissions by judging the quality of the water in the river, without measuring firm-specific emissions. Thus, agreements based on aggregate emissions are feasible, supported, for instance, by imperfect taxes on one of the inputs. Moreover, if the distortions produced by agreements are smaller than those produced by imperfect taxation, agreements will be favorable to taxation. This will always be true in the special case of identical firms, in which agreements lead to efficiency.

Appendix

Proof of Proposition 1

This proof can be divided into three parts:

(1) Show that (4) has a solution for sufficiently low values of σ and high values of δ.
(2) Derive some properties of this solution, and show that it also solves (2).
(3) Given the two first parts, show that the proposed equilibrium constitutes an equilibrium.

Part 1: To simplify the exposition we make the innocent assumption that the maximum of $f(z)$ is obtained at $z = 0$ (we also assume that Z is unimodal). Let $X^{\min} = \bar{X} - \sigma z^{\max}$ (recall that $z^{\max}$ is the maximum of the support of z). Thus, if $X < X^{\min}$, we know with certainty that the observed value of X is less than the target $\bar{X}$. From (1) we know that $P'(X) = f((\bar{X} - X)/\sigma)(1/\sigma)$. It follows that we can write (4) as

$$\pi_i'(x_i^a) = f\left(\frac{\bar{X} - X}{\sigma}\right)\frac{1}{\sigma}(\Pi_i^a - \Pi_i^t)\delta \ . \tag{9}$$

We look for a solution which is such that $X \in [X^{\min}, \bar{X}]$. Since f is unimodal we know that the right-hand side of (9) is increasing in this interval.

For a given X define $x_i(X)$ by (9). It follows that $x_i(X)$ is strictly decreasing in X. Let $G(X) \equiv \sum_{i=1}^{n} x_i(X)$. For sufficiently low values of σ and sufficiently high values of δ it follows that $G(\bar{X}) < \bar{X}$. Since

$f(z^{\min}) = 0$ it follows that $G(X^{\min}) > X^{\min}$. From Brouwer's fixed-point theorem it follows that the equation $G(X) = X$ has a solution in the interval $(X^{\min}, \bar{X})$. Furthermore, since $G(X)$ is strictly increasing it follows that this solution is unique on this interval.

Part 2: Let us next show that for any equilibrium with interior solution, P goes to zero as $\sigma \to 0$. Suppose not. Then, for sufficiently small values of σ, any firm could reduce the probability of taxes to zero by an (infinitely) small reduction in its emissions, which must increase its profit. However, then we cannot be in equilibrium.

Let us make sure that the first-order conditions define a global maximum. Suppose a firm finds it beneficial to deviate, but in such a way that $P < 1$. We then know that $X > \bar{X}$ and hence that $P > 1/2$. However, for low values of σ this cannot be optimal. Suppose therefore instead that the firm deviates and sets its emission level to x_i^0. For low values of σ this implies that $P = 1$. The discounted loss in the next period will then be equal to $\delta[\pi_i(x_i^a) - (\pi_i(x_i^t) - tx_i^t)]$, which must be greater than the gain in the current period, $\pi_i(x_i^0) - \pi_i(x_i^a)$. However, this holds by assumption.

Finally, note that if a violation of the target implies that the government switches to taxes forever, the loss from deviating will be

$$\frac{\delta[\pi_i(x^a) - (\pi_i(x_i^t) - tx_i^t)]}{1 - \delta}$$

which converges to infinity when $\delta \to 1$ as long as the nominator is positive, i.e., as long as $\pi_i(x_i^a) - (\pi_i(x_i^t) - tx_i^t) > 0$.

Part 3: By construction, x_i^a defined by (2) is an optimal action for firm i given that the policy measure that period is negotiated agreements and that the action for the other firms j are x_j^a, $j = 1, \ldots, n$. Furthermore, as x_i^t is optimal for all i if the state of the world is taxes, the proposition follows.

Acknowledgments

We would like to thank Michael Hoel for comments and the Norwegian Research Council for financial support through the program SAMRAM.

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