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NOTA DI LAVORO 108.2000

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Abstract

Collective environmental agreements (CEAs) refer to agreements negotiated between a group of polluting firms and a public regulatory body. The article analyses some potential problems with CEAs.

First, we study free-riding. We show how the incentive constraint imposed by moral hazard determines the maximum feasible emission reduction under a CEA. When firms are short sighted, free-riding seriously undermines the effectiveness of a CEA. Adding uncertainty about environmental damage or future government action makes it even harder to satisfy the moral hazard constraint.

Second, we show that cooperation on a different activity can reduce the incentives to free-ride, since firms can threaten to stop cooperating in order to deter deviations. This effect could explain why some CEAs may be successful. However, we also show that reciprocally the adoption of a CEA increases the possibilities for cooperation on other activities. This might be socially harmful if it translates into price collusion, for example.

Finally, we explore the issue of how firms might allocate the abatement effort toward the collective target. We show that a CEA can help firms to coordinate on a reduction of quantity and a consequent price increase in order to benefit from implicit cartel profits.

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Our findings thus provide some cautionary arguments against the use of CEAs.

JEL Classification: D62; L51; Q28
Keywords: voluntary agreements, free-riding, collusion, cost-effectiveness

1 Introduction

Recent environmental policy relies to a large extent on voluntary approaches. Examples in the United States include the Environmental Protection Agency's 33/50 Program and Project XL. The European Commission's Fifth Framework Programme of Action and Policy encourages the use of voluntary environmental agreements. Several member states have concluded industry-wide environmental agreements in different sectors. The Netherlands, in particular, has a long experience of this form of regulation which forms an integral part of its National Environmental Policy Plan (Ministry of Housing, Spatial Planning and the Environment, 1994). A well-known typology categorizes voluntary approaches into three groups: unilateral commitment by firms, public voluntary schemes that call for commitment to some standards set and controlled by an external authority in return for subsidies or technical assistance, and finally, negotiated agreements between firms and a public regulatory body (Börkey, Glachant and Lévêque, 1999). In this paper we investigate negotiated agreements between the regulator and a group of polluting firms, what we term collective environmental agreements (CEAs). Some practical examples of this approach are the agreement between the European Commission and the European Car Manufacturers Association on emission targets for new passenger cars (European Commission, 1998), the agreement signed between government and the Dutch chemical industry, the Danish agreement on recycling of transport packaging, and the German Declaration by Industry and Trade on Global Warming Prevention (European Environment Agency, 1997). The efficiency and environmental effectiveness of a CEA is thus of practical importance, as well as of theoretical interest. The article's objective is to analyse whether CEAs can obtain a given environmental target at minimum social cost. We thus investigate the effectiveness of the approach, without examining whether the stipulated target is socially efficient. The focus on effectiveness seems justified in that it resembles the situation administrators most often have to confront: choice of implementation instrument for a given, politically determined target.

What results can be drawn from previous research on the efficiency and environmental effectiveness of environmental agreements? There are now some research results on the efficiency of environmental agreements. Schmelzer (1999) analyses the bargaining process between the regulator and a firm and shows under which conditions the abatement target will be inferior to the one obtained under a Pigovian tax. A seminal model of voluntary approaches

(Segerson and Miceli, 1998) shows how the outcome of a voluntary agreement and its efficiency depends upon three factors: the strength of the regulatory threat, the cost of public funds and the allocation of bargaining power between the regulator and the firm. Wu and Babcock (2000) is one of the few existing comparisons of the relative efficiency between a public voluntary scheme and mandatory regulation.

However, previous analyses disregard issues of non-compliance. Here we are concerned with conditions for compliance with the environmental goal, in order to draw some conclusions on the effectiveness of the policy. We therefore extend the standard modeling to a dynamic model of multiple firms. Since environmental agreements most often allow firms a certain time before the target should be obtained, it seems necessary to use a dynamic framework to assess the effectiveness of the approach. Furthermore, a multiple firm framework allows us to analyse issues related to free-riding and to the efficiency of the burden-sharing among firms. Some of the caution about using a CEA stems from standard game-theoretic results related to free-riding and collusion, and we shall detail these results in order to gain a better understanding of a positive question (how such an agreement can function) as well as a more normative one (what is the best design for CEAs). Recently, Segerson and Dawson (1999) and Dawson and Segerson (2000) extended the Segerson and Miceli (1998) model to include multiple firms. Segerson and Dawson (1999) investigate free-riding in a static model with the assumption that abatement costs are lower under a voluntary environmental agreement than under mandatory regulation. In Dawson and Segerson (2000), the alternative regulation to which a CEA is compared is an emission tax. The results indicate that although free-riding is inevitable, this does not hinder the target to be obtained. However, total social costs are higher than under an emission tax, and thus, the voluntary agreement (explicit or implicit) is not a cost-effective instrument. We reach a similar conclusion based on a dynamic model with a general cost structure. Relevant differences will be indicated when necessary. In particular, our focus is on mechanisms that can deter free-riding, thus suggesting ways to design more effective CEAs. Also, related to the standard categorization of voluntary approaches, the motivation of our analysis is somewhat different. Whereas Wu and Babcock (2000) analyse public voluntary schemes, and Segerson and Dawson (1999) unilateral initiatives by firms with the objective to pre-empt regulation, our focus is explicitly on the category of negotiated environmental agreements, in particular CEAs.

Our model of CEAs aims at capturing the following important characteristics:

1) The commitment is collective. It generally originates in a group of firms belonging to the same industrial sector.

2) There is a quantified target for collective emissions, to be met at a given year.

3) CEAs are negotiated with the regulator under the threat of more constraining regulation, such as an emission tax.

4) There are no explicit sanctions in case of failure; an implicit sanction is the threat of an emission tax.

5) Firms freely decide how to share the abatement effort.

Since one of the main concerns with CEAs is that potential free-riding might undermine its effectiveness, we start by defining the term. We distinguish two forms of free-riding: *intra-* and *inter*-group free-riding. First, *intra-group* free-riding can occur when there are no explicit sanctions in case of failure of the CEA. Some signatories may then choose to free ride on other firms' effort. Models of environmental agreements (Moen and Golombek, 1998; Segerson and Dawson, 1999) normally rely upon some tacit threat to discipline firms, for example a future tax, quota or some technology standard. In Section 2.1 of the paper, we use a repeated game context to show that the threat of future taxation indeed can be an effective means of preventing free-riding if firms take a long term perspective. We identify conditions for the maximum feasible emission reduction under a CEA and show how it depends upon discount factors, and the combination of the CEA with other regulation, such as individual emission quotas. In Section 2.2, we extend this basic dynamic model of a CEA to include uncertainty about the implementation of the threat. The uncertainty can be interpreted in two different manners: either government switches to more lenient regulation because of political pressure (or even an outright change of administration), or there is some genuine uncertainty about the environmental damage which leads to a re-appraisal of the optimal tax in the second period of the game. In any case, adding an element of uncertainty reduces the effectiveness of the CEA.

The analysis in Section 2 assumed that firms do not have access to any other penalties than those specified in the CEA. In Section 3 we develop the idea that cooperation on a secondary independent activity can provide the signatories of a CEA with means to punish any deviating firm (Spagnolo, 1999). Threatening to stop cooperation on the secondary activity can then be used by firms to implement more ambitious emission reductions. The secondary activity can involve either price collusion or be of a more socially beneficial nature, i.e. cooperation in research and development (R&D). We analyse both forms of cooperation and argue that the exclusion from an R&D consortium constitutes a credible threat that can be used to discipline firms. The conclusions of Section 3 suggest that it could be useful to formally link participation in R&D programs on abatement technology with CEAs.

The basic policy message is thus to suggest some institutional features that can make CEAs more effective and deter intra-group free-riding. Still, there remains the possibility of *inter-group* free-riding. If the CEA offers the withdrawal of some otherwise mandatory regulation for the entire sector, including non-signatories, it is clear that non-signatories are better off. In order to avoid the problem of inter-group free-riding, the regulator has to impose the standard regulation on firms that do not join the CEA. The withdrawal of the mandatory regulation is thus transformed from a public good to a club good available only for signatories of the agreement. Millock and Salanié (1997) show that efficient regulation then is comprised by a CEA for cooperative firms and an emission tax on non-cooperative firms in order to screen firms when the regulator cannot anticipate whether firms will succeed in cooperating or not. However, another argument can be made for the taxation of firms outside of an existing CEA. Since exerting effort to abate emissions in a CEA is costly, firms outside of the agreement need to be taxed to ensure a level playing-field (Baumol, 1999). The presence of external competitors does however impose a limit on the amount of price collusion that the firms within the CEA can engage in. In the last part of the paper, Section 4, we go on to show the trade-off between the success of a CEA in reaching the environmental quality objective and its effect on price.

To summarize, this paper highlights some differences between CEAs and emission taxes. We identify the factors that enable ambitious emission reductions under a CEA, and suggest some measures that can minimize the problem of intra-group free-riding. However, although there are circumstances under which the environmental objective will be met, the CEA may not minimise costs since its use can favour price collusion and an inefficient sharing of abatement effort.

2 Using cooperation to regulate a group of firms

In this Section, it is assumed that firms cannot use any other sanctions than those specified in the CEA to deter deviations. We exhibit a constraint that a CEA must satisfy in order to succeed, and we discuss the shape and implications of this constraint.

We model a given group of n identical firms as follows. Each firm i gets the profit $\pi(e)$ if its emission level is e. The function π is assumed concave. A regulator can use two instruments: either an emission tax t, based on individual emission levels, or a CEA specifying a constraint on aggregate emissions, $\sum_i e_i \leq E$. Since the observation of individual emissions is costly, a CEA might appear more efficient. The question we ask is: given a target E, is it feasible to reach it using a CEA, and what factors determine the effectiveness of the CEA? We assume that the burden-sharing between firms is efficient.[1] Denote each firm's share of the emission target $e_1 = E/n$, and assume that $\pi'(e_1) > 0$ for all i.

2.1 Incentives for cooperation under the threat of more stringent regulation

The setting of the game is the following, given the basic assumptions. Initially, a regulator and a group of firms negotiate a CEA characterized by the aggregate emissions objective E. At the end of the first period, the regulator can measure the aggregate target and appraise the success of the CEA. If the voluntary agreement is successful, it is assumed to continue unaltered. If the collective objective is not met, the regulator implements a standard emission tax t; once created, this tax remains valid for all subsequent periods. This setting captures the common characteristic of environmental agreements being negotiated under the threat of more stringent regulation if not successful. Given the game described above, each firm can choose to comply with its emission share e_1, thus getting a constant profit $\pi(e_1)$ per period. The firm can also choose to deviate to a higher level of emissions, knowing that consequently the CEA will fail. Our model thus assumes that other firms cannot detect a deviation on time to compensate for a deviating

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[1] Section 4 examines the burden-sharing between firms.

firm.[2] Denote e_0 the best deviation. It can be the maximum of π, or the maximum emission level allowed by law according to an emission quota, for example. Denote δ the discount factor. Then a firm chooses to comply if and only if

$$\pi(e_1) \geq (1-\delta)\pi(e_0) + \delta \max_e [\pi(e) - te] \tag{1}$$

A first conclusion follows immediately from equation 1 :

Proposition 1 *A higher sanction t, or a higher discount factor, or a less ambitious policy ($e_1$higher), make the constraint on participation in the CEA easier to satisfy. Further, imposing individual quotas e_0 in conjunction with the CEA helps to deter deviations.*

According to Proposition 1, CEAs should only be used in sectors where firms display a high discount factor. The role of the discount factor underlines the importance of studying a dynamic game, in contrast to the existing literature. Indeed we will show how the maximum feasible emission reduction under a CEA depends upon a comparison between the discount factor and the proportional emission reduction.

To go further, let us consider that the regulator cannot credibly commit to using taxes higher than a threshold t^*, associated with an emission level e^* such that $\pi'(e^*) = t^*$. In other words, e^* is the best target, and reducing emissions below e^* is a dominated decision, in any case. Then the regulator should commit to the highest possible sanction $t = t^*$, in order to relax constraint (1). This constraint can then be simplified into

$$\pi(e_1) \geq (1-\delta)\pi(e_0) + \delta[\pi(e^*) - t^* e^*] \tag{2}$$

Finally, we get that the best policy e^* can be implemented by a CEA only if

$$\pi(e^*) + \frac{\delta}{1-\delta} t^* e^* \geq \pi(e_0) \tag{3}$$

This constraint is a moral hazard constraint. One has to give some incentives to firms to exert abatement efforts. Note the role of the quota e_0. Also, the

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[2] Segerson and Dawson (1999) assume that firms can detect a deviating firm and choose to make up for its effort before the regulator assesses the overall outcome of the agreement. A peculiar result of the modeling is that the stronger the threat of regulation, the fewer firms will participate in the voluntary abatement effort, which seems contradictory to observed practice.

constraint can be rewritten

$$\frac{\delta}{1-\delta} \geq \frac{\pi(e_0) - \pi(e^*)}{\pi'(e^*)e^*} \tag{4}$$

Interestingly, the right-hand-side of equation 4 is not necessarily decreasing[3] with e^*. Also, due to the concavity of π, one gets

$$\frac{\pi(e_0) - \pi(e^*)}{\pi'(e^*)e^*} \leq \frac{e_0 - e^*}{e^*} \tag{5}$$

so that a sufficient condition for e^* to be implemented successfully by a CEA is

$$\delta \geq \frac{e_0 - e^*}{e_0} \tag{6}$$

The right-hand-side can be interpreted as a percentage reduction in emissions. If the emission reduction is a long term goal and firms are not short sighted (display a high discount factor), some sizeable emission reduction is feasible under a CEA. For the example of a 20 per cent emission reduction to be obtained in 10 years, the constraint reads:

$$\delta^{10} \geq \frac{e_0 - e^*}{e_0} \tag{7}$$

Solving for the discount factor shows that a 20 per cent emission reduction is possible under a ten-year long CEA if firms use an interest rate of less than 14.87 per cent, which seems feasible. Note that an inefficient equilibrium always exists, however, in which all firms deviate, whatever the parameters.[4]

The above result rests upon an important assumption, however - that the firms believe government's threat of mandatory regulation is credible. The next section modifies the basic model to include uncertainty about future government action or environmental damage.

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[3] It must be decreasing in the neighbourhood of e_0, and it is also decreasing for quadratic profit functions. In general, the concavity of π is not sufficient to ensure monotonicity.

[4] Free-riding should also reappear as soon as there is some noise on the observation of $\sum e_i$(cf. Moen and Golombek, 1998), or if the punishment is made smoother with respect to E. In this latter case, the slope of the punishment must be made high enough to deter deviations, as explained in Millock and Salanié (1997). Therefore the constraint (3) is likely to be reinforced: CEAs are subject to a moral hazard problem which is difficult to solve.

2.2 CEAs under uncertainty

Uncertainty matters since a future government change may bring about less stringent environmental policy, or allow government to renege on previously announced threats. There could also be scientific uncertainty about the level of environmental damage, which only is resolved in a later period. We study this issue in a simple two-period model.

Environmental damage is now assumed to be a random variable, whose real value government can observe only at the end of the first period. The damage function is simplified to be constant per unit emission. The expectation of unit damage at the start of the first period is denoted d_0:

$$D(e) = de; \qquad \mathcal{E}(D) = d_0 \tag{8}$$

Optimal policy in the second period is an emission tax equal to d.[5] In the first period, the optimal emission tax is equal to the expected value of damage: d_0. The uncertainty on damages $D(e)$ can be interpreted both as real uncertainty about the amount of environmental damages, or as uncertainty resulting from a change in future environmental policy.

The setting of the game is now the following. A CEA is signed at the start of the first period with objective E. If the firms obtain the objective at the end of the first period, the CEA is renewed, this time with the optimal emission reduction $e(d)$, such that $\pi'(e) = d$. At the end of the second period, the setting is similar to the basic model. The CEA is renewed implying individual emission shares $e(d)$ if successful; if not, an emission tax equal to d is introduced. If the firms fail to obtain the objective E at the end of the first period, the regulator imposes an emission tax d directly in the second period.

The modified model now entails two incentive compatibility constraints. Once the environmental damage of emissions is known, at the end of the first period, constraint 6 applies, just like in the basic model. We will assume that this constraint always holds. However, there is now an additional, different incentive compatibility constraint which has to be verified in the first period:

$$\pi(\frac{E}{n}) \geq (1-\delta)\pi(e_0) + \delta\left[\mathcal{E}\left\{\pi(e(d)) - de(d)\right\}\right] \tag{9}$$

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[5] It is straightforward to include a cost of public funds, $\lambda > 0$, in the model. The subsequent second-period emission tax would be $\frac{d}{1+\lambda}$.

Based on a comparison with the incentive compatibility constraint without uncertainty, in equation 1, the following result is proven in appendix:

Proposition 2 *Uncertainty about the actual damage or uncertainty about the stringency of future government action decreases the effectiveness of a CEA compared to an emission tax equal to the expected value of damages.*

Compared to the case analysed in Section 2.1, the incentive compatibility constraint in the first period is now much harder to satisfy for the same aggregate objective E. Uncertainty on environmental damage or future government action thus further limits the effectiveness of a CEA.[6] It should be noted that we do not include any uncertainty about abatement cost, a factor that could speak for the use of a CEA to develop future technologies. In the absence of uncertainty on the cost side, however, general uncertainty about the environmental damage does not act in favour of using a CEA rather than an emission tax.

The result may also explain why there typically are no formal sanctions in currently observed CEAs. Once the regulator obtains knowledge about the real environmental damage such sanctions may no longer be credible. Nevertheless, this absence of formal sanctions in case the CEA fails limits the effectiveness of the same agreement in comparison with an alternative policy imposing an emission tax equal to the expected value of damages, d_0.

3 Collusion on a related activity as a means of sustaining cooperation in emission reductions

The previous section assumed that firms could not use penalties to deter intra-group free-riding. The success of a CEA was analysed as one equilibrium outcome of a repeated game where the common discount factor is sufficiently high. This section studies in detail another explanation for cooperation in emission reductions: the use of collusion in a related activity. We show how cooperation on a secondary activity increases the likelihood that the CEA obtains its target.

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[6] It is feasible that introducing irreversibility in cumulative damage may be an argument in favour of a CEA, contrary to this model. We leave such an extension for future research.

The line of reasoning goes as follows. If firms are to sustain cooperation and reach a collective emissions target, they need to be able to observe deviations and have access to a credible threat punishing any firm that deviates. In this context, the use of trigger strategies relying upon the loss of profits from a secondary activity can constitute a credible threat. A first effect is that the existence of multiple equilibria on a secondary market can be used to sustain cooperation in emission reductions. A second effect is that the use of a CEA can actually increase the possibilities for collusion on the secondary activity.

Firms are assumed to interact in both the emission reduction game, and another unrelated activity. This secondary activity could be socially desirable, such as joint R&D, or be of a more negative character such as illicit price collusion on another market. The important assumption for the analysis is that it is independent of the firms' emission levels. We shall say that firms collude when they are able to sustain some cooperation on this secondary activity. This can happen if

$$R_C \geq (1-\delta)R_D + \delta R_0 \tag{10}$$

where R_C is the profit from collusion, R_D is the best possible deviation, and R_0 is the profit in the absence of collusion. Recall that equation (1) takes a similar form.

Consider now the following strategy: cooperate in emission reductions and in the secondary activity as long as everyone else does so; if anyone deviates, then revert to non-cooperative behaviour on both activities (so that the CEA fails). The following condition ensures that such strategies form an equilibrium:

$$\pi(e_1) + R_C \succeq (1-\delta)[\pi(e_0) + R_D] + \delta \left[\max_e [\pi(e) - te] + R_0\right] \tag{11}$$

Clearly (11) is obtained by adding (1) and (10). This means that the two effects introduced above are present. First, the existence of collusion on a secondary activity helps to relax constraint (1). The possibility of reverting to the Nash equilibrium in the secondary activity provides an incentive for firms to co-operate in emission reductions. We think that such a factor is prominent in the decision to promote a CEA, and can explain why it might succeed despite the weakness of sanctions.

Second, it is possible that (11) holds although (10) does not. In other words, the creation of a CEA may induce some collusion on secondary activities. Clearly these effects would not hold under an emission tax, since then there is no need to foster cooperation. The main result of this section can be summarized as follows:

Proposition 3 *The existence of cooperation on a secondary activity facilitates the implementation of a CEA. Reciprocally, the creation of a CEA could induce cooperation on the secondary activity, even if none existed before.*

It should be noted that the secondary activity could involve positive *cooperation* (for instance R&D) as well as negative *collusion* in the form of price-setting. In the latter case, the regulator has to assess whether the effects on welfare from increased collusion balance the gain in environmental quality from a successful CEA. The next two subsections are devoted to an analysis of the respective cases.

3.1 Cooperation in R&D

The analysis above assumed that the two activities were independent, which created the additive incentive compatibility constraint. Baumol (1999) discusses the case of positive externalities from R&D activities, arguing that participants can exclude non-contributing members at relatively low cost to themselves. Hence the trigger strategy of threatening to stop cooperation on a R&D project seems to be a credible threat that could sustain cooperation in a CEA, much in the same way as Spagnolo (1999) identifies how social links can improve cooperation on an independent secondary activity. Salmons (1999) suggests that participation in a cooperative R&D programme on abatement technologies should be linked to an environmental agreement on emission reductions. In that case, the secondary activity is no longer independent of the emissions game. Is it possible that linking an inter-related R&D activity to a CEA can increase its effectiveness in obtaining the target? Here, we propose a simple manner of formalising the issue.

At time t=0, each firm i commits R&D expenditures R_i. At t=1 they choose emission levels and at t=2, an aggregate measure is taken to appraise the result of the CEA, after which firms decide to share the results of the R&D activities. Assume the simplest case, where each firm's expenditure is identical and equal to R. When the firm cooperates in both activities, its profits in future periods now depend also on its outlays in the R&D consortium: $\pi(e_1, R)$, with $\frac{\partial \pi}{\partial R} < 0$, $\frac{\partial^2 \pi}{\partial e \partial R} > 0$. The payment is similar to an up-front participation fee enabling the firm to share future R&D results from the cooperation. The strictest form of penalty that other firms can inflict upon a deviating firm is to bar it from future R&D results. The individual firm's incentive compatibility constraint then takes the following form:

$$\pi(e_1) + \frac{\delta}{1-\delta}\pi(e_1, R) \geq \pi(e_0) + \frac{\delta}{1-\delta}\max_e \left[\pi(e, 0) - te\right] \tag{12}$$

The firm's best deviation in the emission game is, like before, denoted e_0. However, the penalty from deviating implies that the firm cannot gain access to jointly developed emission reducing technologies (although it does avoid the R&D fee): $\pi(e_0, 0)$. Contrast equation 12 with the firm's incentive compatibility constraint when other firms cannot bar a firm from sharing the future results of the R&D activity:

$$\pi(e_1) + \frac{\delta}{1-\delta}\pi(e_1, R) \geq \pi(e_0) + \frac{\delta}{1-\delta}\max_e \left[\pi(e, R) - te\right] \tag{13}$$

With R&D activities permitting the firm to reach a higher profit for any level of emissions, the RHS of equation 13 is larger than 12. The intuitive result thus holds that cooperation is easier to sustain when firms can exclude any deviating member in the CEA from a joint R&D activity. Furthermore, the threat is credible since remaining firms still enjoy the benefits of the R&D activity.

The result rests on some strong assumptions: the firms are able to detect a deviating firm before sharing the results from the R&D programme, and there are no scale effects in the R&D program decreasing the benefits to participating firms if one member leaves the programme. Nevertheless, we believe that the result is strong enough to suggest linking R&D programme participation to a CEA, with explicit clauses that sharing in the results only is available to firms contributing to the emission reduction target. The advantage resides in the ease of creating an institutional structure that will strengthen firms' cooperation in the CEA.

3.2 The relation between the effectiveness of a CEA and price collusion

Here, we study the negative aspect of the trigger strategy for implementation of cooperative emission reductions - how the existence of a CEA makes it easier for firms to sustain collusion on price (although explicitly prohibited by law in most countries). Denote a firm's profit as a function of both emissions and its production price, given that other firms adopt price $\overline{p}$: $\pi(e, p; \overline{p})$. Price collusion implies abiding to a price $p_1 > p_0$, where p_0 denotes the competitive market price. Firms can use a trigger strategy in which any deviating firm is punished by reversion to the non-cooperative equilibrium in the product market. When contemplating deviation in both the emission reduction game and in the price game, the firm's incentive compatibility constraint reads :

$$\pi(e_1, p_1; p_1) \geq \max_{e,p} \pi(e, p; p_1) + \frac{\delta}{1-\delta} \left[\pi(e, p_0; p_0) - te\right] \tag{14}$$

A deviation on price is thus punished by the double penalty of a reversion to the non-cooperative equilibrium in both the price game and the emission reduction game. Is this a credible threat? It is, since a deviation on price implies a quantity increase and hence an increase in emissions. The CEA will then fail if the rest of the participating firms do not choose to increase their effort. It is highly unlikely that remaining firms would make up for any deviating firm's effort, since they are penalized both in the price game as well as by the additional abatement cost incurred. Therefore, the threat of a failure of the CEA following a deviation on price is credible. As a consequence, CEAs tend to facilitate price collusion.

Our finding that CEAs can favour the adoption of collusive behaviour can be related to Brau and Carraro (1999). Brau and Carraro (1999) survey the issue of voluntary agreements and market structure and find three ways in which voluntary agreements can have an impact on market structure: by encouraging collusion, by acting as a barrier to entry, and by changing the distribution of costs across the industry. Here, we have proposed a simple manner to model the link between collusion and the adoption of a CEA.

4 Burden-sharing

In this Section, we assume that firms' incentive compatibility constraint holds in order to study the problem of allocation of emission reductions among the group, and its relation with competition on the product market. Recall that most CEAs originate from professional associations, comprising firms belonging to the same industrial sector. It is then legitimate to wonder whether the use of a CEA could modify the outcome of competition on the product market.

More precisely, consider a group of n firms producing an homogeneous good. Firm $i = 1..n$ is characterized by a cost function $C^i(e_i, q_i)$, specifying the cost of producing q_i when allowed emissions are e_i. Denote total quantity $Q = \sum q_i$. Assume that the inverse demand function $P(Q)$ be decreasing.

Now set an emission target E. By definition, a burden-sharing of E is a vector of emissions $(e_1, .., e_n)$ such that $\sum e_i \leq E$ and $e_i \geq 0$ for all i.

Our focus is on how the choice of a burden-sharing modifies the outcome of competition. We therefore ignore the issues of free-riding and implementation studied in the preceding sections: once a burden-sharing is chosen, each firm is supposed to abide by its quota. Equivalently, firms could sign a binding contract specifying emission levels. In any case, the choice of the burden-sharing involves strategic considerations, because firms anticipate its impact on competition.

So let us consider that the burden-sharing is chosen at the beginning of a period, and is followed by a competition game which ultimately determines production, price and profits. This game is parameterized by the chosen vector of emissions. Because the design of environmental policies closely depends on whether competition is perfect (price-taking firms) or not (Cournot competition)[7], we leave the game unspecified and simply assume that:

- the group of n firms is given, without entry or exit considerations. In particular, we assume internal solutions (positive quantities and emissions for all firms).
- There exists a one-to-one relation between the set of feasible burden-sharing and the set of equilibrium quantities.

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[7] For example, imperfect competition may call for differentiated emission taxes. An important literature studies this point and similar ones; see for example Conrad and Wang (1993).

The first assumption is made for the sake of simplicity, and could certainly be relaxed. In particular, external competitors not participating in the CEA could be taken into account through the demand function. The second assumption is less standard in the literature. It specifies that for each burden-sharing, there is a unique (pure-strategy) equilibrium in the competition game. Therefore we can define $\mathcal{Q}$ as the set of equilibrium production vectors. The assumption also stipulates that for each vector $q \in \mathcal{Q}$, there exists a unique burden-sharing $(e_1, .., e_n)$ sustaining it as an equilibrium of the competition game. Therefore there exists functions $(f_1, .., f_n)$ defined on $\mathcal{Q}$, such that for any firm i, $e_i = f_i(q)$. The following examples show that these assumptions are verified under perfect competition and under Cournot competition.

Example 1: suppose that cost functions are convex, and that the inverse demand function $P(Q)$ (where Q is total production) is decreasing. Then given any burden-sharing there exists a unique competitive equilibrium. It is such that

$$\forall i \quad C_q^i(e_i, q_i) = P(\sum q_j) \tag{15}$$

Assume further that marginal costs are decreasing with respect to allowed emissions, or equivalently that competitive supplies are increasing with respect to emissions. Then one gets

$$\mathcal{Q} = \{q \qquad s.t. \forall i \quad C_q^i(0, q_i) \geq P(\sum q_j) \geq C_q^i(+\infty, q_i)\} \tag{16}$$

One can then define $f_i(q)$ as the unique emission level e_i verifying $C_q^i(e_i, q_i) = P(\sum q_j)$.

Example 2: under the same assumptions, suppose Cournot competition (with a unique equilibrium). Then $f_i(q)$ is the unique emission level e_i verifying $C_q^i(e_i, q_i) = P(\sum q_j) + q_i P'(\sum q_j)$.

4.1 Characterizing the surplus-maximizing policy

At this stage two remarks are noteworthy. First, the choice of burden-sharing is strategic because it allows firms to select a particular outcome in the set $\mathcal{Q}$. In the examples above, this set is quite large because we ignore all implementation problems; and consequently strategic effects are likely to be important (see the next subsection). Second, the existence of a competition game constrains also the regulator's policy. For example, given an emission target E, total quantity Q must be below $Q_1(E)$, obtained by maximising the sum of quantities under the constraints

$$q \in \mathcal{Q} \quad \text{and} \quad \sum f_j(q) \leq E$$

Also, the 'competition constraints' ($e_i = f_i(q)$) appear when one minimizes total cost:

$$\sum C^j(f_j(q), q_j)$$

under the constraints

$$q \in \mathcal{Q} \quad \text{and} \quad \sum f_j(q) \leq E \quad \text{and} \quad \sum q_j \geq Q$$

For Q and E given, this defines a cost function $\mathcal{C}(Q, E)$. Given E, the surplus-maximising global quantity is determined through the maximization of

$$S(Q) - \mathcal{C}(Q, E)$$

where S denotes consumer's surplus ($S'(Q) = P(Q)$), under the constraint that $Q \leq Q_1(E)$.

In fact, this constraint is likely to be binding. That is, given a target E, the equilibrium which maximizes total quantity traded should also maximize total surplus. To show this result, two arguments are needed. First, the derivative of $\mathcal{C}$ with respect to Q should generally be less than the maximum marginal cost $\max_j C_q^j$. Second, most competition games display equilibria with insufficient production: $C_q^j \leq p$ for all j. By transitivity this shows that

$$\frac{\partial \mathcal{C}}{\partial Q} \leq S'(Q) = P(Q)$$

so that the optimal policy chooses to maximize the quantity traded: $Q = Q_1(E)$.

Example 1 (continued): suppose firms are identical, with cost functions

$$C(e, q) = c(e) q^{\alpha}.$$

Assume $c'(e) < 0$. Convexity requires $\alpha > 1$ and $c''c(\alpha - 1) \geq c'^2\alpha$. The equalization of marginal production costs to price yields

$$e_i = f_i(q) = c^{-1}(P(\sum q_j)q_i^{1-\alpha}/\alpha)$$

so that

$$C(f_i(q), q_i) = P(\sum q_j)q_i/\alpha$$

The surplus-maximising policy is given by

$$\operatorname{Max} S(\sum q_j) - P(\sum q_j)\sum(q_j)/\alpha$$

under the constraints that $q \in \mathcal{Q}$ and $f_i(q) \leq E$. But the maximand is increasing with respect to the sum of quantities. This shows that the regulator should choose to maximise traded quantities.

4.2 The effect of allowing binding agreements on emissions

Let us turn to firms' negotiation on the burden-sharing. Significant difficulties may arise, due to the imperfections of the negotiation process. Furthermore, if transfers across firms are difficult to implement, then participation constraints play an important role. This implies that abatement efforts need not be allocated efficiently. Rules-of-thumb such as proportional allocation of efforts are then likely to be chosen.

Nevertheless it must be underlined that giving the power to negotiate on burden-sharing has strategic effects. In particular, firms might benefit from choosing an allocation of efforts which reduces quantities offered and finally raises the price.

Consider for example the case when transfers across firms are possible, maybe because some research joint-venture was set up. Or assume that firms are identical and that the competition game is symmetric, so that firms agree to maximise total profits. Given a target E, firms should then maximize

$$P(Q)Q - \mathcal{C}(Q, E)$$

Denote $Q_M(E)$ the solution. By construction, $Q_M(E)$ is less than the maximal quantity $Q_1(E)$. Further $Q_1(E)$ is increasing with respect to E. Therefore there exists $E_0 < E$ such that $Q_M(E) = Q_1(E)$.

Proposition 4 *Consider a CEA with target E. When transfers across firms are possible,*

i) efficient negotiation yields a successful CEA, with observed emissions $E_0 \leq E$.

ii) Given total quantity, the sharing of effort is the one which would have been chosen by a surplus-maximizing regulator.

iii) Given the target E, total quantity is smaller than the quantity which would have been chosen by a surplus-maximizing regulator.

This proposition highlights the importance of the right given to firms to negotiate on emissions. This represents an important device for reducing supplies and raising the equilibrium price. The proposition also explains why such agreements should appear, even in the absence of governmental threats. The following example shows that firms could mimic perfectly a pure monopoly.

Example 1 (continued): since

$$\mathcal{C}(Q,E) = P(Q)Q/\alpha$$

firms will simply maximise revenues $P(Q)Q$, which yields a solution Q_M. Note that Q_M is the monopoly quantity. Further, it can be implemented as an equilibrium as soon as $c(0)$ is high enough (see (16)).

4.3 Inefficient burden-sharing

The preceding result is somewhat extreme, because it assumes that firms are given the right to sign agreements specifying emissions well below the target E. This part relaxes this assumption and studies the outcome of negotiation when only agreements specifying $\sum e_i = E$ are allowed.

According to Proposition 4, there is now a trade-off between reducing quantities (which yields lower emissions: $E_0 < E$) and the fact that the constraint $\sum e_i \leq E$ must be binding. It is easily understood that this trade-off is solved by introducing inefficiencies in the burden-sharing.

Though surprising, this idea can be illustrated by an example. Suppose that polluting plants can be either obsolete or modern. Obsolete plants have high emissions, which could be reduced at a low cost, without modifying much the marginal cost of production. Modern plants have low emissions, and reducing them further would be very costly, both in absolute terms and because this would raise the marginal cost of production. Efficiency would require reducing emissions from the obsolete plants; but then the supplies will be large, yielding a low equilibrium price. However, by reducing emissions mostly on modern plants, supplies are reduced, and the equilibrium price is raised.

Example 1 (continued): firms now maximise $P(Q)Q$ under the constraint that $\sum f_i(q) = E$. For $E_0 < E$, this constraint forces firms to allocate production and emission efforts inefficiently. Indeed, a higher production $Q_1(E)$ could be obtained while keeping total emissions E constant.

4.4 Related literature

We have shown that negotiation and pre-commitment give some market power to firms, who can strategically use an inefficient burden-sharing to get higher prices, and finally higher profits. In a different model of bargaining between a regulator and an industrial organisation, Lehmann (1999) reaches a similar conclusion that voluntary agreements can offer an implicit form of cartelization benefitting industry. These results support the view that CEAs allow for anti-competitive agreements, and our analysis links this view to the use of an inefficient burden-sharing. The conclusion should nevertheless be tempered by the presence of non-signatory firms that play a competitive game. This seems to indicate that CEAs only should be used for sectors exposed to international competition. CEAs that are applied to entire industrial sectors, for instance, on the level of the European Union, may lead to anti-competitive behaviour and an inefficient sharing of the abatement effort.

5 Conclusions

The paper analysed a dynamic model of firms engaged in a collective environmental agreement under the threat of stricter regulation if the cooperative agreement failed to implement the environmental objective. The question we analysed is whether a CEA effectively can obtain a given target. One of the main concerns speaking against the use of a CEA is free-riding. Two different types of free-riding were defined with relation to a CEA. First, some firms may not sign an agreement (inter-group free-riding). In order to avoid inter-group free-riding, the regulator should impose the standard regulation (for example an emission tax) on non-participating firms. Second, in the absence of explicit sanctions in case of failure of the CEA, there are also incentives for participating firms to free ride on each other's effort (intra-group free-riding).

We analysed a dynamic multi-firm model and derived the moral hazard constraint that has to be fulfilled if firms are to implement a CEA. We showed how the moral hazard constraint determines the maximum feasible emission reduction under a CEA. The outcome depends on a comparison between the discount factor and the percentage emission reduction. One conclusion is thus that CEAs only should be used for firms with high discount factors. The result underlines the importance of studying a dynamic game rather than a static model of CEAs. The analysis also showed the importance of combining a CEA with some other form of regulation, such as a minimum quota.

However, the analysis assumed that a government's threat of stricter regulation if the CEA fails is credible. Therefore, Section 2.2 introduced an extension of the basic model to include uncertainty about either actual environmental damage or the fact that government may be more or less oriented toward the environment in the future. Introducing uncertainty in the first period further undermines the effectiveness of a CEA compared to using, for example, an emission tax equal to expected damage.

In Section 3 it was proposed that cooperation on a secondary activity can strengthen the cooperation on emission reductions and deter intra-group free-riding. If firms are to successfully implement a collective emission reduction target, they need to be able to observe deviations and have access to a credible penalty on any firm that deviates. We showed that the use of a trigger strategy relying upon the loss in profits from a secondary activity can constitute a credible threat. This secondary activity can involve positive benefits, for instance, cooperation on R&D, or be of a negative character in the form of collusion on output price. We exemplified the use of linking R&D activities explicitly to the CEA. Since it costs participants little to exclude a firm from an R&D consortium, this trigger strategy is credible and can work to strengthen cooperation in a CEA. In comparison, negative forms of cooperation on a secondary activity are much less stable because one deviation can trigger a price war. The analysis therefore concluded by a comparison of the credibility of the two different forms of cooperation/collusion as a means of sustaining cooperation in emission reductions.

Section 4 went on to explore the issue of burden-sharing of the collective abatement target. Here we assumed that firms' moral hazard constraint was satisfied in order to concentrate only on possible patterns of burden-sharing under a CEA. We showed how a CEA can enable firms to restrict quantities in an implicit cartelization. However, the presence of non-signatory firms playing a competitive game partially limits the inefficiency. An important policy message is thus that CEAs only should be used in sectors where prices are fixed, either by some regulation or by exposure to international competition.

Contrasting the use of CEAs for industry with its use for environmental policy in the agricultural sector is of some interest. The agricultural sector has a long tradition of cooperation and if environmental problems are local, involving only a limited number of actors, CEAs may be more suitable for use in agricultural policy. When a CEA is used on a small-scale level in the agricultural sector farmers are able to observe each others' effort and use credible sanctions on agents that deviate from the agreement, for example exclusion from the use of common production facilities. Furthermore, since agricultural prices normally are fixed by regulation or determined by world market conditions, the problem of price collusion and inefficient burden-sharing normally would not occur for the use of CEAs in this sector.

APPENDIX

Proof of Proposition 2

First, let us introduce some simplifying notation, denoting the von Neumann-Morgenstern expected utility function by v :

$$v(d) = \pi(e(d)) - de(d) \tag{17}$$

The first and second derivatives of $v(d)$ are:

$$v'(d) = -e(d) < 0 \tag{18}$$

$$v''(d) = -e'(d) > 0 \tag{19}$$

Note that equations 18 and 19 imply that firms are risk loving, a well known fact.

The relative ease of satisfying the moral hazard constraint of a CEA when there is uncertainty depends upon the difference of the RHS of equations 9 and 1, assuming the same policy target. This difference is

$$\mathcal{E}\left\{\pi(e(d)) - de(d)\right\} - \max_{e}\left[\pi(e) - te\right] \tag{20}$$

For a given policy target, optimal emission levels are identical in the two cases, which implies the equality of d and t. Since, by equations 18 and 19, firms are risk loving, the difference in equation 20 is then positive by Jensen's inequality. Hence, compared to 1, the incentive compatibility constraint in the first period is now more difficult to satisfy for the same aggregate objective E.

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