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Participation Incentives and the Design of Voluntary Agreements

by

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Abstract

This paper analyses the conditions under which a group of firms has the incentive to sign a Voluntary Agreement (VA) in order to control its emission flows even in the presence of free-riding by other firms in the industry. For the purpose of this paper it is assumed that free-riders cannot be completely excluded from the expected benefits of the VA, which increase with the number of signatory firms and with the abatement level achieved. The paper focuses on policy design by discussing the features that a VA should possess in order to increase its economic and environmental effectiveness. The results support some important conclusions. First, VAs cannot emerge in the case of a pure public good, i.e. when spillovers are such that all firms benefit from the abatement of the signatory firms. Second, even in the case of partial spillovers, the regulator has to impose a minimum participation constraint for the VA to be signed. In this case, if the minimum participation constraint is met, all firms have an incentive to sign the VA. Third, a VA with a minimum amount of regulation improves welfare with respect to a VA in which firms are free to set their profit maximising abatement level.

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Participation Incentives and the Design of Voluntary Agreements

1. Introduction

Voluntary agreements or voluntary approaches (VAs) can be placed into three main categories[1]: *unilateral commitments*, which consist of environmental improvement programmes established by firms themselves and communicated to their stakeholders; *public voluntary schemes*, in which participating firms agree to standards developed by public bodies such as environmental agencies; and *negotiated agreements*, which are contracts between the public (national, federal or regional) authorities and industry.

The latter two groups of VAs have been widely studied in recent environmental economics literature (Cf. Wu and Babcock, 1999 and the empirical studies reported in Lyon and Maxwell, 2000, for public voluntary schemes. Segerson and Miceli, 1998; Lehman, 1999, for negotiated agreements). However, they are usually represented as a bargaining process between an industry representative and a public regulatory body, generally paying secondary importance to (possible) interactions between the single firms and the industry representative and to the strategic interactions between the different firms in the industry (a few exceptions are Dixit and Olson, 2000; Millock and Salanié, 2000). These interactions between firms which negotiate, directly or through a representative, are important because the benefits that firms gain by adhering to a VA often possess the characteristics of no rivalry and no excludability. As a result a free-riding problem is likely to arise.

As is often stressed (Cf. Brau and Carraro, 2000; Carraro and Leveque, 1999; Lyon and Maxwell, 2000; Börkey, Glachant and Lévêque, 1999; Segerson and Li, 1999), profit maximising firms may decide to sign a VA for two main reasons: (i) VAs can increase market demand and therefore profits by *enhancing firms' green reputation*. (ii) VAs can be used to achieve *regulatory gains*. In this latter case, the profit corresponds to the avoided costs of public regulation aimed at addressing the environmental problem.

In both cases, if the agreement is signed by an industry representative or by a group of firms in the industry, the benefits deriving from the agreement may go not only to the signatory firms, but may also spill over to the other firms (the so-called free-riders). For example, an increased market demand resulting from a green marketing strategy that emphasises the adoption of a new, environmentally-friendly production process, may benefit all firms in the industry, and is not necessarily limited to those which actually adopt the new production process. Alternatively, if a group of firms, by signing a VA, can deter the implementation of a cost-ineffective regulation, the benefit goes to all firms in the industry, not only

[1] See Börkey P., Glachant, M. and Lévêque, F. (1999).

to those which sign the VA. It is true that these benefits can be partly exclusive (it depends on the type of marketing strategy or regulation). But at least a portion of these benefits are acquired also by the firms which do not adhere to the VA.

Hence, a VA has some public good features, i.e. it can be considered as an imperfect public good similar to R&D or knowledge investments. A firm's decision of whether or not to sign a VA is therefore strongly affected by an incentive to free-ride. A free-rider would indeed achieve some, possibly all, benefits without paying any costs. This situation is well-known in public finance and industrial organisation literature. It is often concluded that these incentives to free-ride are so strong that no public good is provided (or no R&D is carried out, or no information is collected). In our case, the incentive to free ride may result in no VA being signed or, if the VA is signed by an industry representative, in firms deciding not to comply with the obligations specified in the agreement.

However, recent literature on the emergence of international agreements on global commons (Carraro and Siniscalco, 1993; Barrett, 1994 and many others) has shown that even in the presence of pure public goods, a number of agents -- in this literature sovereign countries -- may decide to pay the cost of providing the public good (technically, they form a coalition within which the burden of providing the public good is shared). If the public good is imperfect, the coalition size usually increases (Carraro and Siniscalco, 1997; Yi, 1999). It is therefore important to assess whether these results also apply to the case of VAs, and above all under what conditions a "coalitional VA" emerges, i.e. a group of firms decide to sign the VA even if other firms chose to free-ride.

In a recent paper, Segerson and Li Dawson (1999) use the same theoretical framework -- derived from some environmental applications of coalition theory (see the survey paper by Carraro and Moriconi, 1999) -- to analyse under what conditions some (or possibly all) firms within an industry will decide to sign a VA. Their model is similar to the one analysed in this paper, but has a number of differences. In particular, they assume that there are no explicit spillovers between firms, but that the benefit provided by the VA can be obtained only if a given environmental target -- set by the regulator -- is achieved. Hence, each firm knows that the VA will be beneficial only if a group of firms accept to abate to the level of the regulator's industry target. If this is not the case, all firms will be penalised. There is therefore an incentive for some firms to join a coalition in order to meet the target (i.e. to provide the public good) even if the remaining firms free-ride.

The approach adopted in this paper is quite different. First, there is no given environmental target, but the regulator can choose between two different types of VA: one in which firms are free to set their optimal (profit-maximising and regulation pre-emptive) level of abatement, and one in which a minimum level of regulation is imposed in order to guarantee the effectiveness of the VA.[2] Indeed, VAs are often criticised for being cost-effective but environmentally ineffective, because firms within a VA tend to carry out an insufficient amount of emission abatement. In this paper, this criticism is assessed to determine whether this actually holds true, and under what conditions a minimum level of regulation (or other policy measures) should be introduced in the VA. Second, spillovers are included in this model, i.e. the benefits of the VA go to the signatory firms, and also partly to the free-riders. Hence, there is an explicit modelling of the free-riding incentives that enables an analysis of the degree to which spillovers prevent the VA from being signed. Moreover, the costs and benefits that derive from adhering to the VA depend not only on the abatement carried out by a single signatory firm, but also on the abatement carried out by the other firms in the VA. In fact, the benefits increase as more firms join the coalitional VA. This introduces a further form of interaction amongst firms that will be shown to be very important in the following.

The goal of the paper is twofold. Firstly, the features of a coalitional VA, in particular the conditions under which at least some firms sign the VA, will be analysed. Secondly, policy design issues will be dealt with, and ways in which the regulator could design the VA in order to increase both the number of signatories and its economic and environmental effectiveness will be examined.

The results of this paper support some important conclusions. First, VAs cannot emerge in the case of a pure public good, i.e. when spillovers are such that all firms benefit from the abatement of the signatory firms. Second, even in the case of partial spillovers, the regulator has to impose a minimum participation constraint to ensure that the VA will be signed by at least some firms. However, in this case, if the minimum participation constraint is met, all firms will then have an incentive to sign the VA. Third, a VA with a minimum amount of regulation is welfare improving with respect to a VA in which firms are free to set their profit maximising and regulation pre-emptive abatement level. More surprisingly, firms' profits also improve, because a minimum regulation offsets one of the three free-riding incentives that will be shown to characterise this model.

The structure of the paper is as follows. Section 2 describes the main features of the VA model used in this paper. Section 3 analyses the equilibrium of the game and discusses some general properties of the equilibrium coalitional VA. Section 4 further develops the model by assuming a linear market demand and linear-quadratic cost functions. This enables the derivation of some additional results for the equilibrium variables which are important in the identification of the main features of the equilibrium coalitional VA and the discussion of the policy implications of this analysis. Finally, the main results of the paper are summarised in Section 5 in which and some directions for further research are also outlined.

[2] A VA is said to be ineffective, or environmentally ineffective, when the abatement levels chosen by the signatory firms are zero or very low, therefore inadequate to protect the environment.

2. Pre-emptive VAs with Spillovers

In the Introduction, the benefits that firms could reap by signing an environmental VA were mentioned. However the origin of these benefits was not specified. As said, benefits could arise from the reputation enhancing effects induced by the VA which would, in turn, increase market demand, or from the cost reductions achieved through activities devoted either to pre-empting costly regulations or to co-operating in environmental innovations. In the rest of this paper, we will model the likely advantages arising for firms which sign a VA in the form of cost advantages. This approach is general enough to encompass different effects. For example, it captures both genuine production cost reduction (due for example to co-operation in innovation), and relative cost reductions (due for example to the pre-emption of a regulatory threat or to the granting of additional flexibility by a public regulator). In particular, we focus on the case of "pre-emptive VAs". [3]

There are two features of pre-emptive VAs that should be stressed. First, in several cases, the extent to which a VA succeeds in offsetting the implementation of a regulation increases with the level of emission abatement carried out by each signatory firm (Boyd and Blackman, 2000). Second, pre-emptive VAs are also often characterised by some forms of co-operative behaviour amongst signatory firms. For example, Maxwell, Lyon and Hackett (2000) show that firms have an interest in undertaking self-regulatory initiatives in order to influence the regulator's and the citizens' attitude towards mandatory regulation, in particular when a variation in the *ex-ante* regulatory threat is observed. The effects of this lobbying activity increase with the number of firms in the VA. Another example is illustrated by the case in which VA adopting firms agree to a common technological innovation effort in relation to a cleaner production goal (e.g. Aggeri and Hatchuel, 1999). In this case, the innovation effort can be carried out co-operatively and the benefit increases with the number of signatories of the VA (Carraro and Siniscalco, 1997).

The features of a pre-emptive VA which have been described will be accounted for in our modelling framework as follows. First, firms which sign the VA have expected costs which are lower and expected profits which are higher than those in the presence of direct regulation or other non cost-effective policy measures. Second, the expected cost reduction increases as more firms sign the VA and as the abatement carried out by these firms increases.

As explained in the Introduction, this analysis is focused on collective VAs in which a large number of firms may be involved. Hence, it may be the case that only a subgroup of firms belonging to the industry

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[3] As shown for example in Segerson and Miceli (1999), the signing of a VA reduces expected production costs because it reduces the probability of facing a (more costly) direct regulatory regime. We thereby focus our analysis on these types of "pre-emptive VAs", thus neglecting "reputation enhancing VAs", where the benefits for the signatory firms come mainly from demand shifts.

decides to sign the VA. In this situation, in which a coalitional VA emerges, some of the benefits achieved by signatory firms may spill over to the other firms in the industry which have chosen to free-ride. This is another important feature of our modelling of pre-emptive VAs: the benefit that spills over to non-signatory firms is a share β of the benefits achieved by signatory firms, where $\beta \in [0,1]$.

These features of a pre-emptive VA are introduced into an oligopolistic industry with *n* firms which compete *à la* Cournot. Hence, there are three types of externalities: (i) the usual *Cournot externality* that leads firms to excess production at the Nash equilibrium (with respect to the case of cooperative behaviour); (ii) the *pre-emption externality* through which the benefit achieved by a signatory firm increases with the abatement carried out by the other signatories; (iii) and the *public good externality* that enables a non-signatory firm to receive a share β of the benefits produced by the abatement carried out by the firms which sign the VA.

The equilibrium choices of the firms will be analysed taking into account all three of these external effects. In the model, firms are assumed to choose the production level, the amount of emission abatement, and above all whether or not to sign the VA proposed by the regulator. The regulator decides whether or not to propose a VA, and the type of VA. All these choices are sequential and are cast in a three-stage game. In order to simplify the analysis, it is assumed that the regulator is aware that the firms perceive a VA as less costly than other environmental policy measures (e.g. direct regulation). Let it also be assumed that these cost reductions, as compared to direct regulation, are always larger than the cost increases related to the possible lower environmental effectiveness of VAs.

As a consequence, in the first stage of the game, the regulator chooses which type of VA to propose, but it is assumed that the choice of whether or not to propose a VA has already been made. The regulator chooses between two main types of VAs: (i) a VA in which signatory firms are free to choose their profit maximising (and regulation pre-emptive) abatement level; and (ii) a VA in which each firm is required to attain at least a minimum abatement level in order to pre-empt direct regulation.[4]

In the second stage, the *coalition game* takes place. Given the VA proposed by the regulator, firms decide non-cooperatively whether or not to sign the VA. Each firm chooses its profit maximising strategy taking into account the interactions with the other firms, and the implications of the second stage choice for the production and abatement decisions that will be taken in the third stage of the game. Hence, the equilibrium in the second stage is a non-cooperative Nash equilibrium and each firm's strategy space is [to sign the VA, not sign the VA].

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[4] This is just one of the possible forms of minimum regulation that can be introduced in the VA. Another possibility is a minimum environmental tax as in the Danish CO_2 Agreement Scheme (Cf. Chidiak, 1999).

In the third stage, the *Cournot game*, firms choose their Cournot output levels and their optimal abatement levels simultaneously and non cooperatively (with or without the constraint imposed by the regulator on minimum abatement levels).

Let us briefly present the model. Firms compete *à la* Cournot in a *n* firms oligopolistic industry which produces a homogeneous good. Let y_i be firm *i*'s production level. Total output is therefore $Y = \sum_{i=1}^{n} y_i$. The production activity is polluting and firms may therefore plan to carry out some abatement e_i, $i=1,2, \ldots n$. Emission abatement is obviously costly. Let us assume that firms deciding to sign a VA have an expected convex abatement cost equal to $\phi_i(e_i)$, i=1,2, …,n, where $\phi_i'(e_i) = 0$ when $e_i = 0$, $\phi_i'(e_i) \geq 0$ and $\phi_i''(e_i) \geq 0$. However, also marginal production costs can be increased by the firm's abatement decision. Let $\delta_i < 1$ parameterise the increase of marginal production costs induced by the abatement effort.

A symmetric industry is assumed in which all firms share the same technology. As a consequence, the index *i* in the cost functions and related parameters can be dropped. Let "A" indicate an "Agreeing", or VA adopting, firm, whilst "NA" denotes a "Non-Agreeing" firm; $e_{iA} - e_{i0}$ denotes the increase in the abatement level carried out by signatory firms with respect to the business-as-usual level e_{i0}. This latter abatement level will be determined under the assumption that no VA is proposed and signed in the industry.

The crucial element of the model is the cost function. From the above discussion, it is apparent that this must be a function of at least three variables: the number of participants in the VA, their emission abatement levels, and the cost spillovers obtained by both "agreeing" and "not agreeing" firms (or an indicator of the relative size of these spillovers).

Let c denotes the marginal production cost in the business-as-usual situation (i.e. when no VA is introduced). Let us assume that the cost advantages obtained by the VA signatories are proportional to the incremental abatement effort $e_{iA} - e_{i0}$. Moreover, the larger the number of firms which sign the VA, the greater the cost advantages. Hence, the expected total cost function of a signatory firm is:

(1a) $$TC_{iA} = (c + z_{iA})y_{iA} + \phi(e_{iA}),$$

where:

(1b) $$z_{iA} = \delta(e_{iA} - e_{i0}) - \gamma \sum_{k=1}^{K} (e_{kA} - e_{k0}), \qquad \delta < 1,$$

K is the number of signatory firms and the parameter γ can be normalised to one without loss of generality. As a consequence, the expected profit function for firms which sign the VA is:

(2) $$\pi_{iA} = \left\{ P(Y) - \left[c + \delta(e_{iA} - e_{i0}) - \sum_{k=1}^{K} (e_{kA} - e_{k0}) \right] \right\} y_{iA} - \phi(e_{iA})$$

where $P(Y)$ is the inverse market demand function.[5] Given that the benefits produced by adopting the VA spill over, at least partly, to firms which have chosen not to sign the VA, their cost function is:

(3) $$TC_{iNA} = \left[c - \beta \sum_{k=1}^{K} (e_{kA} - e_{k0}) \right] y_{iNA} + \phi(e_{i0}) \qquad \beta \in [0,1]$$

where $\phi(e_{i0})$ is the business-as-usual abatement cost, because both signatories and non signatories may undertake some abatement activities even in the absence of a VA. As a consequence, the expected profit function is:

(4) $$\pi_{iNA} = \left\{ P(Y) - \left[c - \beta \sum_{k \neq 1}^{K} (e_{kA} - e_{k0}) \right] \right\} y_{iNA} - \phi(e_{i0}) \qquad \beta \in [0,1]$$

A few assumptions are also necessary to specify the demand side of the model. Let

(5) $$\begin{aligned} &P(y_i)' - c(y_i)'' < 0 \\ &P(y_i)' + y_i P(y_i)'' < 0 \end{aligned}.$$

be the usual stability conditions (Seade, 1980). Moreover, in order to avoid a "perverse" behaviour by firms which could find it profitable to increase their production costs, we also impose the condition (Seade 1985):

(6) $$E \equiv Y \frac{P(Y)''}{P(Y)'} > -2 \Big/ \left(2 - \frac{y_i}{y^\circ} \right)$$

[5] We will always talk of expected costs and expected profits, because the cost reduction achieved through the VA is relative to the expected costs under a different form of regulation.

where $y°$ is the supply of the most efficient firm after the game has been played.[6] With these conditions, firms have no direct incentive to reduce emissions which do not entail any efficiency gain.[7] These conditions are automatically satisfied when a linear demand case ($E = 0$) is considered.

Let us focus finally on the regulator behaviour. As said, the regulator may impose a minimum abatement level $\overline{e}$ in order to rule out the adoption of "cosmetic agreements". The regulator makes this choice in the first stage of the game, by anticipating the behaviour of firms in the subsequent stages. Hence, the regulator imposes $\overline{e} \geq e_{iA}$ if its welfare function, defined as usual by the sum of industry profits, consumers' surplus and environmental gains, is larger in the case in which a minimum binding abatement level is imposed than in the case in which signatory firms are free to adopt their profit-maximising abatement strategy.

3. Equilibrium Endogenous VAs

In order to compute the equilibrium of the game described in the previous section, let us move backward by starting from the last stage of the game. Let us first assume that no VA is proposed in order to compute the business-as-usual abatement level e_{i0}. The first order conditions in this case are:

(7a) $$\frac{\partial \pi_i}{\partial y_i} = P'(Y)y_i + P(Y) - c = 0,$$

(7b) $$\frac{\partial \pi_i}{\partial e_i} = \phi'(e_i) = 0,$$

from which $e_{i0} = 0$, for $i = 1,2, \dots n,$ at the equilibrium, whereas the equilibrium output coincides with the standard Cournot production level. The intuition is quite simple: in a non-cooperative framework, firms will abate emissions voluntarily only if this does not constitute a net cost for them.

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[6] The upper boundary of this condition is determined by the admissible value of y_i which is closest to 0, thereby leading to $E > -1$. In general, in the presence of asymmetry, a threshold value of E strictly higher than –2 must be assumed in order to rule out the possibility of positive profit changes due to a cost increase.

[7] Actually, a situation in which market structure and demand are such that a firm could find it profitable to deliberately increase its production costs cannot be ruled out as implausible. See Seade (1985), Stern (1987) or Carraro and Souberayn (1996) for a discussion of these cases. An application to VAs can be found in Brau and Carraro (1999).

As a consequence of this result, the expected profit functions can be re-written as:

(8a) $$\pi_{iA} = P(Y)y_{iA} - \left(c - (1-\delta)e_{iA} - \sum_{k\neq 1}^{K} e_{kA} \right) y_{iA} - \phi(e_{iA}) \qquad \text{for } i = 1,...,K$$

(8b) $$\pi_{iNA} = P(Y)y_{iNA} - \left(c - \beta \sum_{k=1}^{K} e_{kA} \right) y_{iNA} \qquad \text{for } i = K+1,....,n$$

where it is assumed without loss of generality that the first K firms sign the VA. The Nash equilibrium values ($y^*_{iA}, y^*_{iNA}, e^*_{iA}$) are obtained from the first order conditions (9), where the index i can be dropped because of the symmetry of the equilibrium. Hence, (y^*_A, y^*_{NA}, e^*_A) are determined by:

(9a) $$P'(Y^*)y^*_A + P(Y^*) = c + (\delta - K)\psi(y^*_A) \equiv C_A$$

(9b) $$-C'_A y^*_A = \phi'(e^*_A)$$

(9c) $$P'(Y^*)y^*_{NA} + P(Y^*) = c - \beta K \psi(y^*_A) \equiv C_{NA}$$

where $\delta < 1,\ 1 \leq K \leq n$, and $Y^* = Ky^*_A + (n-K)y^*_{NA}$. Equation (9b) can be written as:

(10) $$y^*_A = \frac{\phi'(e^*_A)}{1-\delta} = \psi^{-1}(e^*_A) \qquad \delta < 1$$

from which:

(11) $$e^*_A = \psi(y^*_A).$$

Given the convex abatement costs hypothesis, this implies that the abatement level is proportional to the production level and increases with it. Replacing equation (11) into (9a) and (9c), we obtain:

(12a) $$P'(Ky^*_A + (n-K)y^*_{NA})y^*_A + P(Ky^*_A + (n-K)y^*_{NA}) = c + (\delta - K)\psi(y^*_A)$$

(12b) $$P'(Ky^*_A + (n-K)y^*_{NA})y_A + P(Ky^*_A + (n-K)y^*_{NA}) = c - \beta K \psi(y^*_A),$$

where we used again the symmetry assumption and where K, the number of firms which sign the VA, belongs to the interval $[1,n]$.

Equations (12a)(12b) provide the equilibrium output levels that determine the equilibrium abatement level. These equilibrium values can then be replaced in the profit functions (8) to analyse the equilibrium of the second stage of the game where firms decide whether or not to sign the VA, i.e. where K^*, the equilibrium number of signatories, is determined.

Let $\pi_{iA}(K) \geq 0$, $\pi_{iNA}(K) \geq 0$ be the values of the profit functions -- of signatories and free-riders respectively -- when output and abatement assume the equilibrium values determined by eqs. (11), (12a) and (12b). A necessary condition for the existence of an equilibrium coalition (defined by K^* because of symmetry) is that at the equilibrium profits for signatories are larger than profits when no VA is signed, i.e.

(13) $$\Pi_{iA}(K^*) \equiv \pi_{iA}(K^*) - \pi_{iA}(0) \geq 0 \qquad i=1,2, \ldots K$$

This profitability condition must hold jointly with the so-called stability condition (D'Aspremont *et al.,* 1983; Carraro and Siniscalco, 1993; see also the survey by Carraro, 1999):

(14a) $$\pi_{iA}(K^*) \geq \pi_{iNA}(K^* - 1)$$

(14b) $$\pi_{iA}(K^* + 1) \leq \pi_{iNA}(K^*)$$

for all $i=1,2, \ldots, n$. The profitability and stability conditions are necessary and sufficient to define the Nash equilibrium of the second stage of the game.

Hence, when players are symmetric, the equilibrium K^* is the largest integer smaller than the unique root of the stability condition:

(15) $$L(K^*) = \pi_A(K^*) - \pi_{NA}(K^* - 1) = 0$$

such that $L'(K^*) < 0$ and $\Pi_A(K^*) \geq 0$ in the interval $[1,n]$, where the index i has been dropped because of symmetry and where $L(K)$ is called stability function (Carraro and Moriconi, 1999; Hoel and Schneider, 1997).

Notice that, by applying (14), if $L(K) < 0$ for all $K \in [1,n]$, then there is no equilibrium coalition ($K^* = 0$) because the incentive to free-ride $\pi_{iNA}(K-1) - \pi_{iA}(K)$ is positive for all $K \in [1,n]$. Viceversa, if

$L(K) > 0$ for all $K > K_{min}$, $1 \leq K_{min} < n$, then the equilibrium coalition is the grand coalition ($K^* = n$) because the incentive to enter the coalition is positive for all $K > K_{min}$.[8]

Unfortunately, it is not possible to derive an analytical expression for K^* under the above fairly general functional forms. It is therefore necessary to adopt a specific functional form for market demand and abatement costs to analyse the equilibrium of the coalition game. This is the objective of Section 4. There is however a conclusion, which holds whatever the number of firms in the VA, which drives many of the results of the next section.

Let us assume that $\pi_{iA}(K)$ and $\pi_{iNA}(K)$ are concave in K. This is not a strong assumption because profit functions are concave in output because of assumption (5)[9] and output can be shown to be concave in K -- by differentiating eqs. (12a)(12b) -- if abatement costs are sufficiently convex. The intuition is as follows. When K is small, an additional member of the coalition increases the profits of signatories because the benefits of the pre-emption effect is larger than the costs of increasing abatement and output (these two variables are positively correlated as shown by eq. (11)). Notice that an increased output also reduces the equilibrium market price. When K is large, the cost increase is larger then the benefits of pre-empting regulation because this latter effect is linear in K, whereas the cost effect is convex in K. For similar reasons, profits of non-signatories are also convex in K. When K is small, they receive an increasing benefit from the action of signatories which spills over on non-signatories. When K is large, the benefits from spillovers still increase, but the reduced market price negatively affects profits of non-signatories. It can easily be shown that there is a value of K above which profits decrease.

It can also be shown that profits of non signatories start decreasing before profits of signatories and that there exists a value of K above which profits of non signatories are smaller than profits of signatories. Indeed, subtracting equations (12b) from (12a) yields:

$$(16) \qquad P'(Y^*)(y^*_A - y^*_{NA}) = C^*_A(K\psi(y^*_A)) - C^*_{NA}(\beta K\psi(y^*_A)) = [\delta - (1-\beta)K]\psi(y^*_A),$$

which implies that firms which sign the VA produce a higher output if and only if they have a lower marginal production costs. This is the case when $\delta < (1-\beta)K$, or equivalently:

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[8] In this latter case, a coordination mechanism which induces at least K_{min} countries to enter the coalition must be designed.

[9] Strict concavity implies $P(y_i)' - c(y_i)'' + P(y_i)' + y_i P(y_i)'' < 0$, which is clearly implied by (5).

(17) $$K > \frac{\delta}{1-\beta} \equiv K°$$

Hence, only when the group of signatories is sufficiently large, can signatories produce more than non-signatories. In this case, signatories have also a larger market share. Given the positive relationship between profits and output, it is clear that (17) constitutes a necessary condition for equilibrium profits of signatories being larger than those of non-signatories.[10] However, this is not a sufficient condition. We have the latter for a value $K°° \geq K°$, given that, in the profit function (8a), one has to take into account the abatement cost $\phi(e)$. Notice that (17) is more easily satisfied when the spillover rate β is low, and when the abatement cost parameter δ is also low.

Condition (17) is important because it says that, once abatement costs are taken into account, $\pi_A(K) \geq \pi_{NA}(K)$ for $K \geq K°°$, i.e. signatories have profits larger than those of non signatories only if the number of firms which sign the VA is at least equal to $K°°$. Moreover, the positive difference between $\pi_A(K)$ and $\pi_{NA}(K)$ is increasing with K. Notice that the (internal) stability condition is $\pi_A(K) \geq \pi_{NA}(K-1)$. As said above, the function $\pi_{NA}(K)$ is concave and therefore not such that $\pi_{NA}(K) \geq \pi_{NA}(K-1)$ for all $K \in [1,n]$. However, even if $\pi_{NA}(K-1) > \pi_{NA}(K)$, the increasing positive difference between $\pi_A(K)$ and $\pi_{NA}(K)$ implies that there will exist a value $K\hat{} > K°°$ such that $\pi_A(K) \geq \pi_{NA}(K-1)$ for all $K \geq K\hat{}$.

This has the following implication: if $K\hat{} < n$, $L(K) > 0$ for all K such that $n \geq K > K\hat{} \geq 1$. As a consequence, there is an incentive to enter the coalition for all $K > K\hat{}$, $K \leq n$. Hence, the equilibrium coalition is the grand coalition ($K^* = n$), whenever a co-ordination mechanism is introduced which induces at least $K\hat{}$ firms to sign the VA. In words, all firms will sign the VA if at least K^ firms decide to sign it. The next section will prove the same result in the case of a linear demand function by explicitly deriving the value of K^* and will discuss its policy implications.

[10] This conclusion is true independently of ϕ because of eq. (11) which implies that equilibrium abatement is proportional to output and hence abatement costs become a component of marginal costs. As a consequence, the greater the function $\phi(e)$, the lower y^* and therefore the lower e^* and the value of $\phi(e^*)$.

4. Equilibrium Endogenous VAs with Linear Market Demand.

In this section, the value of K^*, the number of firms signing the VA, is determined by analysing the equilibrium of the second stage of the game, in which firms decide whether or not to adhere to the VA proposed by the regulator. As previously said, the model must be simplified in order to explicitly identify the structure of the equilibrium endogenous VA, the role of the different externalities and related free-riding incentives and the impact of changes in the model structure. For simplicity's sake, we present the results obtained with a simple linear inverse demand function: $P(Y)=a-b\cdot Y$. Moreover, the fixed abatement cost is assumed to be quadratic: $\phi(e_i)\equiv g\frac{(e_i)^2}{2}$, where *a,b>0, a>c; g>0*. Using these functional forms, the equilibrium values for output and abatement levels in the third stage of the game become:

(18a) $$y_A^*=\frac{(a-c)g}{bg(n+1)-(1-\delta)\{(n-K)[K(1-\beta)-\delta]+K-\delta\}}$$

(18b) $$y_{NA}^*=\frac{(a-c)\{bg-(1-\delta)[K(1-\beta)-\delta]\}}{b(bg(n+1)-(1-\delta)\{(n-K)[K(1-\beta)-\delta]+K-\delta\})}$$

(18c) $$e_A^*=\frac{(1-\delta)}{g}y_A^*$$

which are positive for all values of K and β if $g\geq\frac{n}{b}$. This condition also implies that reaction functions are negatively sloped (hence, production levels are strategic substitutes).

Before determining the equilibrium K^*, we need to guarantee that changes in the number of firms which sign the VA do not yield negative production costs, i.e. $C_A, C_{NA}\geq 0$ for all $K\in[0,n]$, where now $C_A=c+\delta e_A-Ke_A$ and $C_{NA}=c-\beta Ke_A$. This holds for all possible values of β and δ if $\frac{a}{n+1}\leq c<a$, which guarantees that both C_A and C_{NA} are positive for all $K\in[0,n]$, $\beta\in[0,1]$ and $1\geq\delta\geq 0$.

From the equilibrium output and abatement levels (18), we obtain the equilibrium profit levels:

(19a) $$\pi_A(K) = \frac{\left[2bg - (1-\delta)^2\right]}{2g}(y_A *)^2$$

and

(19b) $$\pi_{NA}(K) = b(y_{NA} *)^2$$

where the already mentioned condition $bg \geq n$ also implies $\pi_A(K) \geq 0$. How do these profits change when K changes? By deriving (19a) with respect to K, we get:

(20) $$\frac{d\pi_A(K)}{dK} = \frac{\left[2bg - (1-\delta)^2\right]}{g}(y_A *)\left(\frac{dy_A *}{dK}\right)$$

Using the equilibrium output level (18a) and a few manipulations, it is possible to conclude that output (and hence the abatement effort and profits) increases when:

(21) $$K \in \left[0, \frac{n}{2} + \frac{(1+\delta)}{2(1-\beta)}\right].$$

Let $\widetilde{K} = \frac{n}{2} + \frac{(1+\delta)}{2(1-\beta)}$. If $\widetilde{K} > n$, then profits increase for all K$\in [0,n]$. If $\widetilde{K} < n$, i.e. if $(\delta + 1) < n(1-\beta)$, then profits first increase and then decrease as K increases from 0 to n. This is important because profits are hump-shaped when $\widetilde{K} < n$. Hence the optimal coalition size, i.e. the profit maximising number of signatories, is smaller than n. As a consequence, firms have an incentive to form a "VA club", i.e. a group of signatories which exclude some firms from the possibility to sign the VA. Notice that $\widetilde{K} < n$ becomes more likely as the number of firms in the market increases. Indeed:

(22) $$\lim_{n\to+\infty}\left(\frac{\widetilde{K}}{n}\right) = \lim_{n\to+\infty}\left(\frac{1}{2} + \frac{(1+\delta)}{2n(1-\beta)}\right) = \frac{1}{2}$$

Finally notice that:

(23) $$\widetilde{K} = \frac{n}{2} + \frac{(1+\delta)}{2(1-\beta)} > K^\circ = \frac{\delta}{1-\beta}$$

for all n, $\beta,\delta \in [0,1]$.

A similar humped-shaped behaviour can easily be detected for the profit functions $\pi_{NA}(K)$ and $\pi_{NA}(K-1)$. The first derivative of $\pi_{NA}(K)$ has only one root in the interval *[0,n]* and it corresponds to a maximum of the function $\pi_{NA}(K)$. Moreover, it can be shown that this value of *K*, say K_1, is smaller than $\widetilde{K} < n$. Finally, K_1+1 is also smaller than $\widetilde{K}$. The proof use the fact that the first derivatives of both $\pi_{NA}(K)$ and $\pi_{NA}(K-1)$ are negative at $K = \widetilde{K}$.

As a consequence, the profitability functions $\Pi_A(K) \equiv \pi_A(K)$ - $\pi_A(0)$ and $\Pi_{NA}(K-1) \equiv \pi_{NA}(K-1)$ - $\pi_{NA}(0)$ are the ones shown in Figure 1 in the case of imperfect spillovers (β < 1). The two functional forms hold for all parameter values that meet the restrictions $\frac{a}{n+1} \leq c < a$ and $g \geq \frac{n}{b}$.

Let us compute the equilibrium K^*. From eq. (13), at the equilibrium firms which sign the VA must increase their profits with respect to the case in which no VA is signed. From eqs. (14a)(14b), the equilibrium of the second stage of the game can be achieved when no firm has an incentive to leave the coalition (not to sign the VA) and no firm has an incentive to join the coalition (sign the VA).

Notice that $\Pi_A(K)$ is positive for all *K* in the interval *[1,n]*, thus satisfying the profitability condition. However, the stability conditions (14a)(14b) are not satisfied. Indeed, the stability function *L(K)* is equal to zero at $K = K_{min}$, but $L'(K_{min}) > 0$ (see Figure 2). In other words, K_{min} is not an equilibrium because there is an incentive to join the coalition for all $K \geq K_{min}$, i.e. $\pi_A(K) \geq \pi_{NA}(K-1)$ for all $K \geq K_{min}$. As a consequence, the equilibrium coalition is $K^* = n$, but only if a coordination mechanism is introduced that induces at least a number of firms equal to the smallest integer greater than K_{min}, (i.e. K^) to sign the VA . Therefore, the result shown at the end of the previous section is further confirmed.

The analysis is easier when β = 1. In this case, the function $\pi_{NA}(K-1)$ is above $\pi_A(K)$ for all K = 1,2, … *n*. Hence, when $\beta = 1$, $L(K) < 0$ for all *K* in the interval *[1,n]*] and there is no equilibrium coalition ($K^* = 0$). The incentive to free-ride is always greater than the benefits deriving from signing the VA. Hence the following proposition holds:

Proposition 1*: The stability function becomes positive for $K > K_{min}$ and its slope is positive, unless $\beta = 1$ (see Figure 2). This implies $K^* = n$. For $\beta = 1$, the stability function is negative and negatively sloped for all $K \in [1,n]$ (see Figure 3). This implies $K^* = 0$.*

This proposition has two important implications:

- If a group of K firms signs the agreement, with $K \geq K_{min}$, then all remaining firms have an incentive to sign the VA, i.e. a band wagon-effect takes place that induces all firms to sign the VA.
- When $\beta = 1$, all benefits from signing the VA go to both signatories and free-riders. Hence, no coalition forms at the equilibrium, i.e. no firm accepts to sign the VA.

These two conclusions have further implications for policy design. How should a VA be designed in order to induce all firms to sign it ? Two recommendations can be proposed. First, the regulator should introduce a minimum participation constraint in the VA. Namely, the VA is operational only if at least a minimum number of firms decide to sign it.[11] Second, the regulator should design the VA in such a way that most benefits can be reaped by signatories, thus minimising spillovers to non-signatories. This can be done, for example, through a policy mix which penalises firms which do not join the VA. Notice that, by minimising β, the regulator not only induces firms to sign the VA, but also reduces the minimum participation constraint which is necessary for all the firms to sign the VA (see Figure 4).

Notice the hump-shaped form of the profit functions shown in Figure 1. This is a consequence of the asymmetry introduced by the VA. Firms which sign the VA have a competitive advantage with respect to the other firms because they enjoy lower marginal production costs (if $\beta < 1$ and when a stable coalition forms). This advantage implies a higher market share, and therefore profits, only if some firms are excluded from the VA. When all firms sign the VA, they all enjoy the same expected cost reduction and therefore have the same market share. Therefore, each firm would like to obtain the benefits provided by the VA, but not to share these benefits with all firms in the market.

This has a further important policy implication. Indeed, if the profit function is hump-shaped, the profit maximising coalition is smaller than the grand coalition. This implies that firms have an incentive to form a coalition which is smaller than the one in which all firms participate. This is not possible under an open membership rule where all firms are free to join or leave the VA, but it may be possible in the case of an exclusive membership rule, where access is conditional to the consensus of the other signatories (see Carraro and Moriconi, 1999). As a consequence, if the regulator's objective is to achieve the largest

[11] This is the so called "alpha rule" or "minimum participation rule" in Carraro, Moriconi and Oreffice (1999).

environmental benefit, he should design the VA in order to prevent firms adopting rules or behaviour that enable them to exclude other firms from the VA. The case is even more ambiguous if the regulator aims to maximise total welfare, because in this case the higher environmental benefit achieved when all firms participate in the VA must be compared to the total profit of the industry which could be lower.

Finally, the number of firms in the industry does not affect either the shape of the stability function, which is increasing for $\beta < 1$ and negative and decreasing for $\beta = 1$, or the value of K_{min} when $\beta < 1$. This implies that, whatever n, if $\beta = 1$ no VA will be signed, whereas all firms will sign the VA if it is properly designed (differentiated benefits, namely $\beta < 1$, minimum participation constraint, which increases with β, open membership). Summing up:

Proposition 2*: Under open membership, either no VA is signed (when $\beta=1$) or all firms sign the VA (if $\beta<1$ and an adequate minimum participation constraint is imposed) whatever the number of firms in the industry.*

It can therefore be concluded that VAs, if properly designed, will be signed by all firms in the industry even in the presence of free-riding, but their effectiveness in terms of environmental control remains uncertain. Indeed, the profit maximising abatement level chosen by signatory firms may be too low. This raises the question of whether a minimum abatement constraint could not only enhance the VA environmental efficiency, but also improve welfare. Indeed, one may argue that a minimum abatement constraint, by increasing firms' abatement efforts, also reduces their output and profits, thus inducing an overall welfare reduction (let us recall that welfare is defined by profits + consumers' surplus + environmental benefits). Hence, a minimum abatement level may not be welfare improving.

This issue can be analysed by solving the regulator's decision problem in the first stage of the game. As previously explained, the regulator chooses between a VA in which firms are free to set their profit maximising, but regulation pre-emptive, abatement level and a VA in which a minimum abatement level is imposed. The regulator will impose a minimum abatement only if: (i) the profit maximising abatement level is below the minimum abatement standard; and (ii) total welfare increases in the presence of a minimum abatement level.

Let us analyse a firm's choice in the third stage of the game when the VA requires the achievement of a minimum abatement level $\overline{e}_A$. If $\overline{e}_A < e^*_A$, then the equilibrium is the one previously derived. If $\overline{e}_A \geq e^*_A$, then a firm chooses only output in the third stage of the game, and the equilibrium is defined by the standard Cournot equilibrium output. Indeed, if emissions by firms which sign the VA are equal to $\overline{e}_A$, the profit functions become:

(30a) $$\overline{\pi}_A = (a - bY)y_A - (c + \delta\overline{e}_A - K\overline{e}_A)\cdot y_A - g\cdot\frac{(\overline{e}_A)^2}{2}$$

(30b) $$\overline{\pi}_{NA} = (a - bY)y_{NA} - (c - \beta K\overline{e}_A)\cdot y_{NA}$$

and the equilibrium output levels are:

(31a) $$\overline{y}_A = \frac{(a-c)}{b(n+1)} - \frac{\{K^2(1-\beta) + (n+1)\delta - K[n(1-\beta)+1+\delta]\}}{b(n+1)}\overline{e}_A$$

(31b) $$\overline{y}_{NA} = \frac{(a-c)}{b(n+1)} - \frac{\{K(K(1-\beta) - \beta - \delta)\}}{b(n+1)}\overline{e}_A$$

In order to guarantee non-negative production levels (and profits) for all firms in the market, whatever K^* and β, we need to impose the following condition: $n\overline{e}_A \leq c \leq a - n^2\overline{e}_A$, which implies:

$$a \geq n(n+1)\overline{e}_A$$

Notice that, as in the case where firms choose their profit maximising abatement level, output of signatories is larger than output of free-riders iff $K(1-\beta) \geq \delta$.

Let us now solve the second stage of the game in which firms decide whether or not to sign the VA proposed by the regulator. In order to determine K^* -- the Nash equilibrium number of firms which join the VA -- we have to compare the profits of signatory firms with those of free-riders. The results for the equilibrium coalition are identical to those obtained in the case previously analysed and summarised by Propositions 1 and 2. Indeed, the presence of a minimum abatement level does not modify the shape of the profit functions of signatories and free-riders. Therefore:

Proposition 3*: Propositions 1-2 derived above for the case of an unconstrained VA hold also in the case of a VA in which a minimum binding abatement level is imposed. Hence, free-riders must be excluded, at least partly, from the benefits of the VA, and a minimum participation constraint has to be imposed, for a coalitional VA to form endogenously. If $\beta<1$ and an adequate minimum participation constraint is imposed, all firms join the VA even in the presence of a minimum abatement constraint.*

Moreover, by comparing the values of outputs and profits when no abatement constraint is imposed, with those when an abatement constraint is introduced in the first stage of the game, we have:

Proposition 4*: If a coalitional VA forms, social welfare can be increased by the introduction of a minimum binding abatement constraint. In particular, there is an interval of abatement levels for which all components of the welfare function, including profits, increase when a minimum abatement constraint characterises the VA.*

This proposition provides us with the solution to the first stage of the game. Indeed, from Proposition 4, the regulator's optimal, welfare maximising, choice is to design a VA with an explicit minimum binding abatement constraint. There are three main reasons for this choice. Suppose $\beta < 1$ and an appropriate minimum participation constraint is introduced. Then all firms sign the VA under open membership. If there is also a minimum binding abatement constraint, then: (i) environmental benefits are higher, because total abatement is higher than the one that firms would carry out were they are free to set their abatement level; (ii) production is also higher because the cost reduction is higher in the presence of an emission abatement constraint.

The reason for this latter result must be found in the externality that the VA introduces in the industry. The VA is such that its pre-emptive effectiveness increases with the number of firms in the VA and with the total size of the their abatement. Hence, when a firm increases its own abatement it benefits the other firms too. In the non-co-operative case, firms are unable to take this external effect into account when deciding their profit maximising strategy. However, a minimum abatement constraint is also a way of inducing firms to exploit this external effect, by moving firms closer to co-operative abatement levels, thus reducing marginal production costs and increasing output levels.

As a consequence of the production increase, consumers' surplus is higher when a minimum abatement constraint characterises the VA. Finally, there is an interval of emission abatement levels for which profits are also higher, because in this interval the increase in profits induced by a larger production dominates the abatement cost increase. Hence, all three components of the social welfare function may increase when a minimum abatement constraint is imposed within the VA.

5. Conclusions

The analysis carried out as part of this paper has identified the conditions under which a regulator can offset the free-riding incentives that may undermine the chances of implementing a VA within an industry. Moreover, the regulator can modify the design of the VA in order to enhance its environmental and economic effectiveness. The features that a VA should possess in order to be environmentally and economically effective are as follows.

- The expected benefits of the VA (in terms of regulatory pre-emption, technological co-operation, etc.) should go mainly to the firms which sign the VA. Free-riders should, at least partly, be excluded from these benefits (e.g. they are taxed whereas signatories are not).
- A minimum participation constraint should be introduced for the VA to be operational, i.e. for firms to enjoy its expected benefits (e.g. direct regulation or taxation is not introduced only if a sufficient number of firms sign the VA).
- A minimum abatement level should be introduced to avoid "cosmetic" emission abatements, but also to offset the negative effects on production and profits of a non-cooperative behaviour on abatement levels.
- If the environmental objective is particularly relevant, the regulator should also impose open access to the VA in order to exclude an anti-competitive, discriminatory use of the VA by firms.

It is believed that these results are valuable in the design of collective, or industry wide, VAs in cases where market structure and the related strategic interactions between firms are properly taken into account. Whilst these results are mainly derived from the analysis of a linear-quadratic model, they are based on an incentive structure which supports the quantitative conclusions achieved through our simplified mathematical analysis from a qualitative point of view. Indeed, the coalitional VA which emerges at the equilibrium is determined by:

- The free-riding incentive induced by the (possibly partial) public good nature of the VA. This could suggest that a coalition is unlikely to be formed. Or that, if formed, it is likely to be small (Carraro and Siniscalco, 1993; Barrett, 1994). However, there is a second incentive:
- The cost effectiveness of the VA increases with the number of firms in the VA and with the size of their abatement levels. This induces a band-wagon effect such that all firms would like to join the VA if free-riders can be partly excluded from the cost advantages produced by the VA (otherwise the VA is a pure public good) and if a minimum coalition size is reached (which implies that a sufficient cost differential with respect to free-riders is achieved).

However, these two effects do not guarantee that the VA is environmentally effective. The reason for this is that firms have a further incentive:

- If regulation is pre-empted regardless of the abatement effort, then firms will minimise this effort in order to maximise profits. Hence, the regulator must impose a minimum abatement constraint. In doing so, the regulator paradoxically also increases firms' profits because it induces firms to adopt abatement levels closer to their co-operative levels (which cannot be achieved by firms within a non-co-operative decision-making framework).

There is a final incentive that must be taken into account when designing the VA:

- Firms in the coalitional VA achieve the highest profit level when a sufficiently large group, but not all of them, sign the VA. Again, this is an incentive which is independent on the specific mathematical framework adopted in this paper. It arises because a VA produces both an absolute and a relative cost advantage. This latter advantage disappears when all firms sign the VA. Hence firms in the VA have an incentive to discourage other firms from joining. This obviously reduces the environmental effectiveness of the VA. As a consequence, the regulator may find it useful to impose restrictions on exclusive strategic behaviours by firms which sign the VA.

Based on the above, it can be argued that our conclusions have a general validity, which goes beyond the mathematical model analysed in this paper, and this could help policymakers in their efforts to improve the effectiveness of their environmental policy tools. Moreover, this entire analysis is strictly non-co-operative, namely all decisions taken by firms are taken independently and non-co-operatively. The decision to join the VA is therefore strictly voluntary and only dependent on the incentive structure outlined above. Incentives to participate in the VA determine the equilibrium outcomes and drive these policy conclusions.

Further research is still necessary in this field. For example, in a sequel to this work, it is hoped that it will be verified whether similar results can be obtained when the VA is adopted to enhance firms' "green reputation" and therefore to increase market demand. It would also be interesting to explicitly give firms the possibility to collude on abatement and/or output levels. Finally, an analysis of the adoption of VAs in an industry with asymmetric firms would also be very informative.

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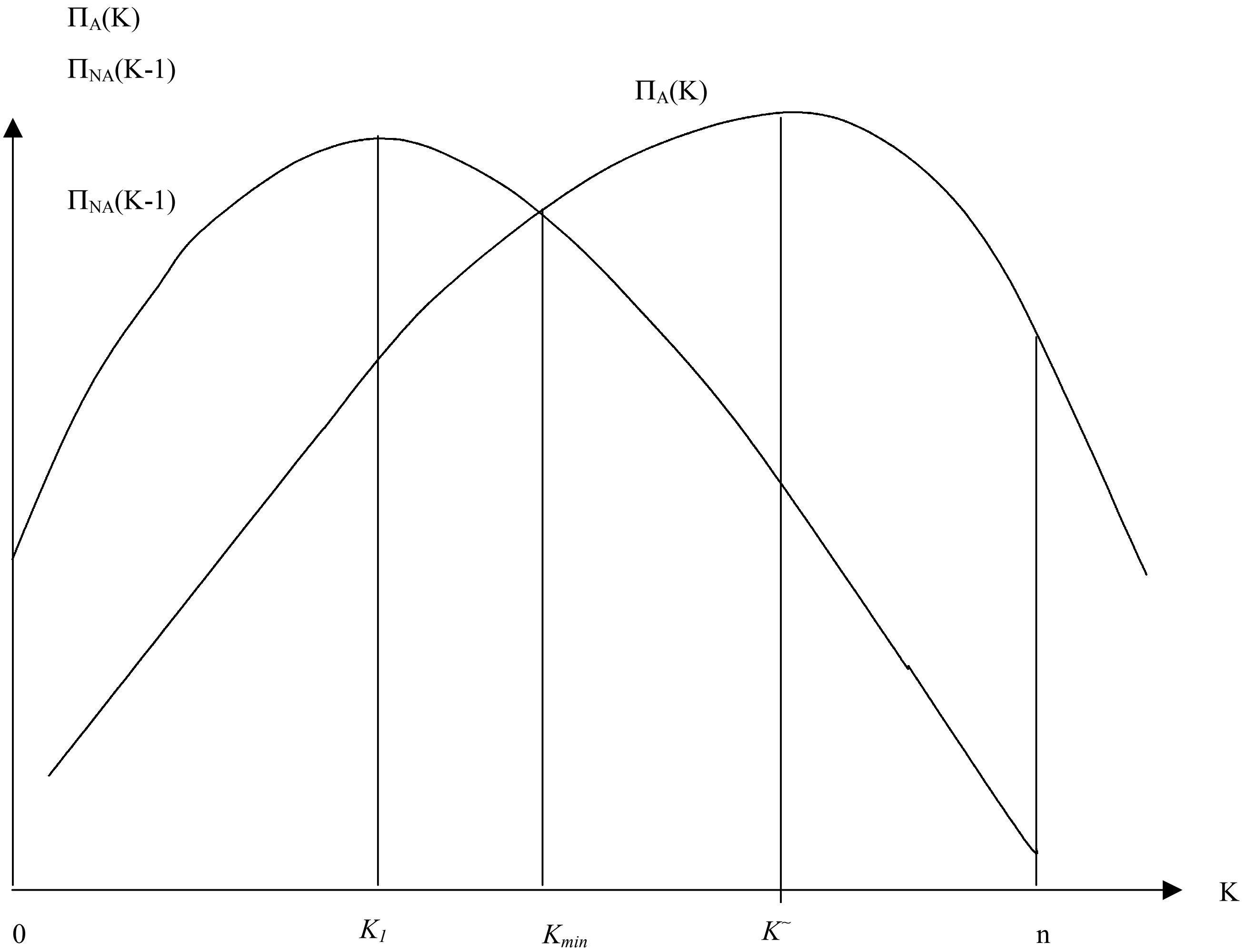

Figure 1. The shape of the functions $\pi_A(K)$ and $\pi_{NA}(K-1)$ for $\beta < 1$.

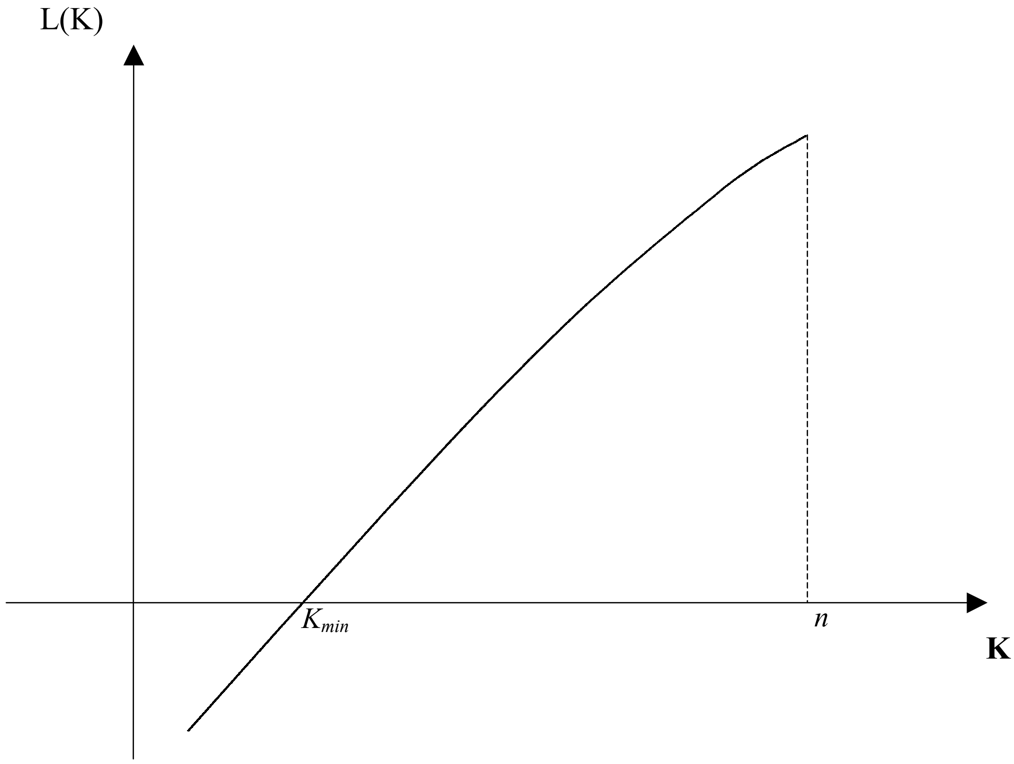

Figure 2: The stability function of an unconstrained VA for β<1 .

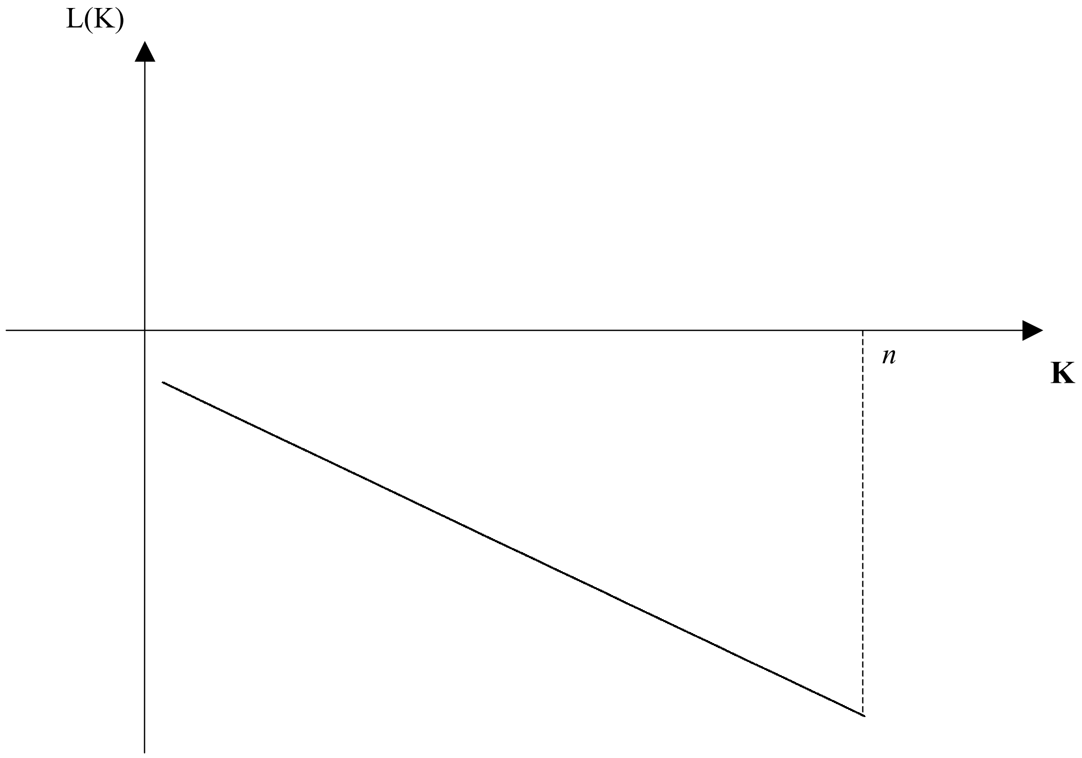

Figure 3: The stability function of an unconstrained VA for $\beta=1$.

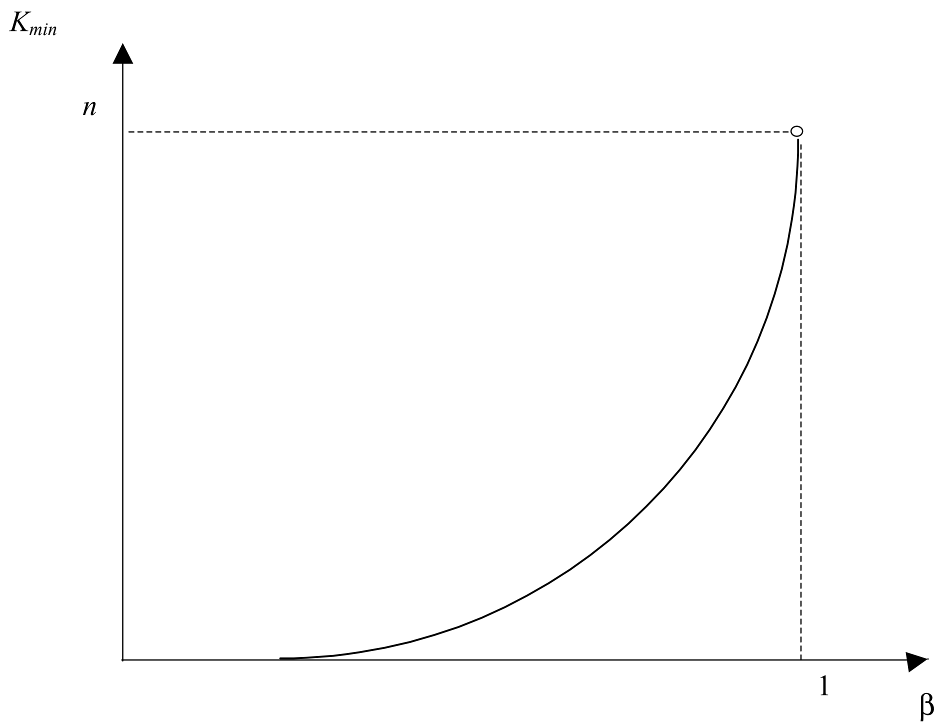

Figure 4: The effects of the spillover β on the minimum participation K_{min} in an unconstrained VA.