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Game structures and equilibrium condition in environmental regulation games with heterogeneous players

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Abstract

"Voluntary Approaches" to environmental protection are environmental policy instruments that have been implemented in different European countries.

As main characteristic this instruments are "voluntary in nature", meaning that the participating firms have the option to participate or not to participate, and after the program is implemented they maintain the option of abandoning it at any moment.

Firms' participation in this "voluntary actions" is explained through three potential benefits ─ internal efficiency improvements, commercial image improvements and public regulation "capture" ─ that assume characteristics of imperfect "public goods", opening the door for free-riding.

At the same time the empirical experiences on Voluntary Approaches show that the private participation is normally done by groups of firms. Combining this reality with the "voluntary nature" and the creation of internal non-excludable benefits we face the existence of a "collective action phenomenon".

We analyse this "collective action" phenomenon that supports the implementation of the "Voluntary Approaches" in a four stage regulation game with two heterogeneous groups of firms. Our objective is to identify the game structures that are created and characterise the equilibrium conditions

I. Introduction

Recent theoretical developments on the field of environmental policy extended the toolbox for planning environmental regulation adding to the traditional public regulation instruments, which are non voluntary in nature, a new breed of privately participated instruments, voluntary in nature (In Box 1. we make a brief presentation of the non-voluntary approaches and the voluntary approaches to environmental policy Box 1.).

Box 1. The environmental policy instruments toolbox

Non Voluntary Approaches: traditional regulation methods where the environmental regulation is impose to the firms by the government, and they are legally obliged to comply with it.

To implement this "public regulation" based approach there are the traditional environmental policy instruments[1] (OECD, 1989):

- **Command and control instruments (direct regulation):** institutional measures that aim to directly influence the environmental performance of the polluter, regulating the implementation of process or the characteristics of products, restricting or prohibiting emissions of pollutants, imposing a given technology or a choice between a group of technologies, and\or restricting the economic activity.

  The main feature of these instruments is that "there is no other choice left to the polluter: he has to comply, or face penalties in judicial and administrative procedures" (OECD, 189, page, 12).
- **Market based instruments (economic instruments)**: institutional measures that affect the costs and revenue of the economic agents, with the purpose of influencing their decisions pressing for an efficient management of environmental resources.

  These instruments "as contrary to direct regulations, leave actors free to respond to certain stimuli in a way they themselves think most beneficial" (OECD, 189, page, 12 and 13).

Voluntary Approaches (VAs): environmental improvement programmes in which firms have the freedom to choose if they want to participate or not, and after they accepted the set of environmental objectives included in the programme they still have the option to abandon it at

[1] Besides these two instruments that are traditionally considerer, the European Commission in the text of the 5th Environment Action Programme for the European Environmental Policy also considers: *Horizontal Support Instruments* - public regulation instruments based on education and information diffusion; and, *Financial Support Instruments* – public-regulation instruments based on the financial support to environmental aware actions like R&D processes on environmental technologies.

any moment.

The Voluntary Approaches are implemented through co-regulation or auto-regulation process using the following instruments (Carraro e Lévêque, 1999, pages 2 e 3):

- **Unilateral commitments**: an environmental auto-regulation process that "consists of environmental improvement programmes set up by firms themselves and communicated to their stakeholders."

  Objectives, obligations, implementation and monitoring procedures are decided by the firms. It is possible that the firms consent for stakeholders' participation in the definitions of the environmental objectives. They my also delegate the monitoring to a third party.
- **Public voluntary schemes**: "Within this type of Voluntary Approaches participating firms agree on the standards (related to their performance, their technology or their organisation) which are developed by environmental agencies".

  In the "scheme" it is established the conditions for individual participation, the provisions to be complied with by the firms, the monitoring criteria and the evaluation of the results, as well as the economic benefits in the form of R&D subsidies, technical assistance, and improved reputation resulting from the use of a eco-label.
- **Negotiated Agreements**: "These are contracts between the public (national, federal or regional) authorities and industry". They contain an environmental objective and a schedule for implementation, both negotiated by the parties.

  The agreement can be legally binding (assuming the form of a contract) or not.

  Together with the "public voluntary schemes" the "negotiated agreements" are also environmental co-regulation processes.

The most interesting characteristic of VAs is its "voluntary nature". (Has it is defined in box 1.) These instruments are "voluntary in nature", not only, because the participation from the firms is voluntary, but also, because the participants can abandon the environmental program at any time (having only to deal with the specific penalties that where negotiated for the specific programs).

The economic explanation for firms' voluntary participation in such an environmental protection program is in the three types of benefits that can be associated to a proactive approach to "environmental management":

- first, a firm may profit from a **productivity improvement**: through a better allocation of the "environmental resources" and/or the implementation of new

technologies that are, simultaneously, "cleaner" and more efficient (Porter and Linde, 1995, Constança, 1997);

- second, firms can **improve their image** in the different markets: in the commercial markets, the "environmental aware" attitude improves the relation with consumers and other stakeholders (Arora and Carson, 1995), in the financial market, an environmental responsible action can be associated with better economic performance and smaller economic risk;
- finally, firms may **reduce the regulation compliance costs:** when acting voluntary in the preservation of the environment, firms may convince the environmental public regulator that there is no need to strength public regulation or implement new one; in these sense through voluntary action firms can achieve a more flexible public environmental regulation, a delay in it's implementation or even it's "capture" (Léveque. F, 1996).

Another interesting feature of VAs is the structural modifications to the regulation process that they introduce.

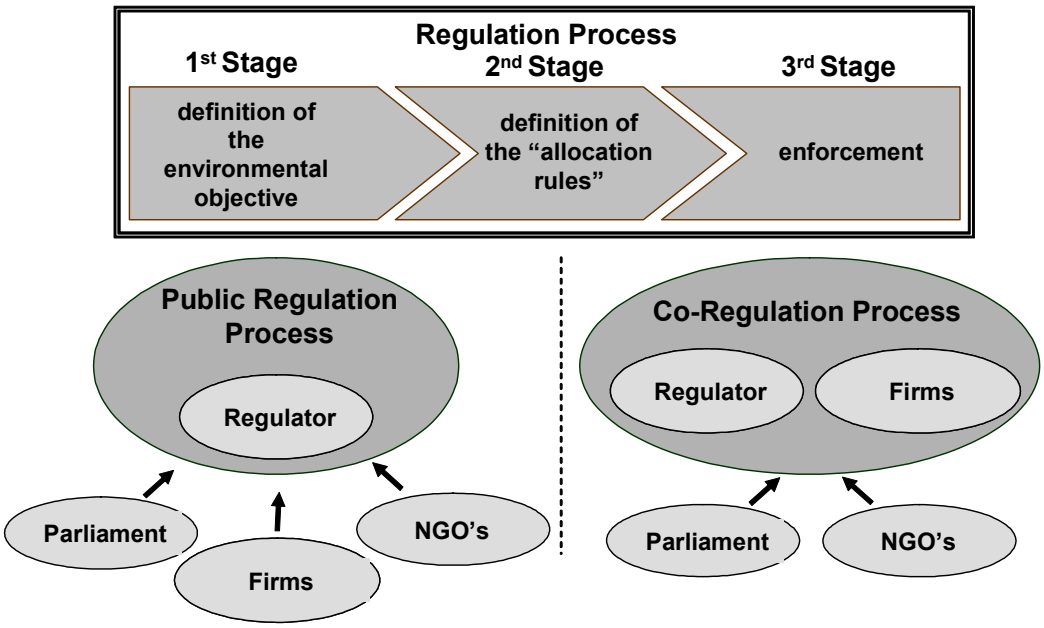
In Box 2 we present a very simple model (developed under the influence of the paper by Hansen, 1996), where we confront the public regulation process (that supports the non-voluntary approaches) with the co-regulation process (that implements the voluntary approaches), highlighting the principles differences.

The first scheme establishes that the regulation process is composed by three consequent stages: definition of the environmental objective, definition of the "allocation rule" and enforcement.

In the scheme related to the public regulation case, the regulator is presented as the sole responsible for all the regulation process suffering different pressures: institutional pressures by the parliaments, political pressures by the NGO's and political and economical pressures by the firms.

In the co-regulation process, the firms assume an active roll in the different stages. This situation affects, not only, the results in each stage but, also, the types of pressures that each agent exercises and suffers. Part of the political pressures suffered by the regulator is now exercised over the firms in the form of commercial impacts. The regulator has also the opportunity to share the regulation costs with the firms (the polluter) especially on the enforcement stage. In this way the firms are placed in the centre of the regulation process, turning there environmental behaviour more visible.

Box 2. Public regulation *versus* co-regulation



The empirical observation of most of the VAs experiences in European allows us to identify another interesting characteristic of the co-regulation structure: the private involvement in the regulation processes is not restricted to the participation of a sole firm but is normally participated by a group of firms that belong to the same industry.

In reality, in most of the VAs it is actually a representative of the group of firms (e.g., an "industrial association") that controls the negotiations for its creation and then supports the implementation. Adding

Putting together all this information we can establish that in a VA process we normally find a group of firms that voluntary agrees to participate in a process that creates a public good (the "preservation of the environment") and, simultaneously, can create benefits for each one of them and/or for all the polluters group.

We are, in this way, facing a "collective action" process in environmental regulation. To be more precise we are facing a collective action phenomenon associated to the use of VAs in environmental policy.

In this paper our aim is to present a game theoretical model that allows us to better understand the "collective action" phenomenon that supports VAs creation.

In the next section (II) we will start by presenting the Portuguese experience in VAs, which represents our empirical motivation; then we make a reference to the theoretical background that supports our work (III), and finally we will present three section (IV,

V, VI) dedicated to the development of our environmental regulation game model. In these three last sections we intend to explore the game structures and de equilibrium conditions of such games considering two groups of n heterogeneous players. Being this part of an ongoing work, we do no present a conclusion but we rather make a reference to the possible further developments.

II. The empirical motivation: the Portuguese Example

The Portuguese Environmental Authorities turned to Voluntary Approaches for the first time in 1988/1990. (Box 3).

This first experience included a group of four environmental agreements signed by the Portuguese Environmental Agency (DRA) and by Industrial Associations representing: the pulp paper industry (1988), leather industry (1989), glass packaging industry (1990) and the paper packaging for liquids industry (1990). All four agreements aimed at reducing the environmental impact of these industries in a period till 1992 (that was later extended to 1995).

Due to the success of this first experience a "Global Protocol on Environment and Sustainable Development" was signed, in 1994, creating a framework for the implementation of further Voluntary Approaches.

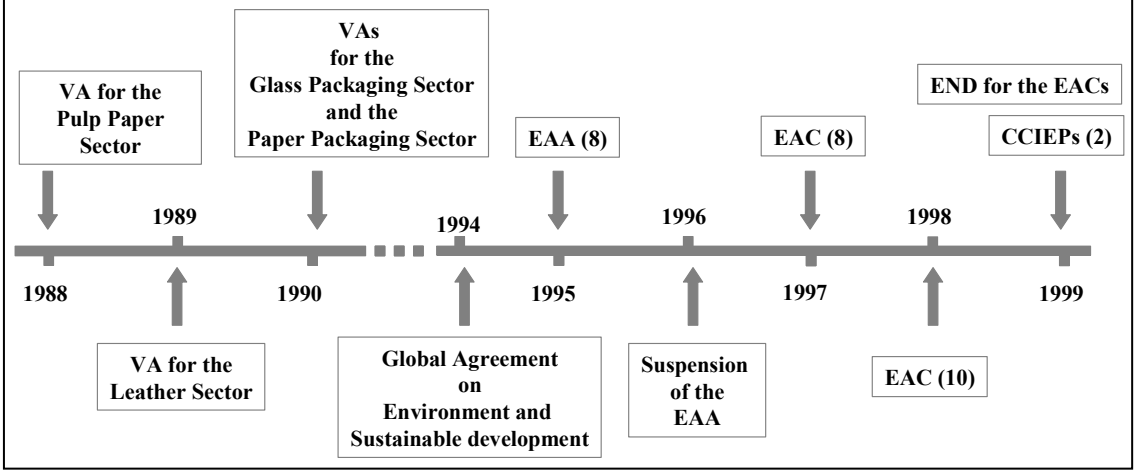
In this document it was clearly stated that the "environment quality" was an important part of the public and private economic policies towards competitiveness, and it was recognized that the environmental protection efforts should obey to principles of "precaution", "co-responsibility" and "co-operation".

Both public and private entities acknowledge the necessity to make considerable investments in "environmental protection". Under the principles of co-ordination and co-operation, the public authority also recognised the important of creating incentive schemes to supported firm's efforts in this field.

Voluntary Agreements were specified as preferential environmental policy instruments, capable of incorporating these principles and demands.

Supported by the Global Protocol a second generation Voluntary Approaches were implemented in 1995 with the creation of the Environmental Adaptation Agreements (EAA).

Box 3: Voluntary Approaches in Portuguese Environmental Policy



The EAAs were introduced as complementary instruments to public regulation.

As the name implies, these agreements were signed with the particular intention of programming a gradual adjustment of the participating firms to the environment regulation that was applicable at the time. There where 8 EAAs implemented:

- one regional agreement: between the Portuguese Environmental Agency (at that time the DGA, *Direcção Geral do Ambiente)* the Portuguese Industrial Agency (at that time the DGI, *Direcção Geral da Industria)* and the companies that adhere to a treating wastewater system in the region of Águeda;
- and seven industrial agreements, signed by industrial associations representing the following industrial sectors: metallurgical and metal-mechanic; vegetal oils; chemicals; marble, granite and similar industries; dairy products; tomatoes; hog raising.

Even though this was an important step to confirm the voluntary instruments as part of the Portuguese environmental policy, the lack of legal support to the enforcement of the EAAs condemned them to an unavoidable failure.

It was necessary to change the legal status of the instrument and to place it under the framework of the "public administrative law" to re-establish the credibility of the Voluntary Approach. This was accomplished with the implementation of the Environmental Adaptation Contracts (EAC), in 1996.

Maintaining the same objectives eight EACs where signed during 1997 and ten at the beginning of 1998 (even though many other negotiations began but fail to be completed):

- In 1997 four contracts were signed replacing EAA from 1995 — for the industrial sectors of vegetable oils, chemicals, decoration stones, dairy products — together with four new contracts for the olive oil, textiles, paper and wood industrial sectors.
- In 1998, the tomato sector EAC replaced a 95 EAA, and nine new contracts were created for the industrial sectors of shoes manufacturing, plant protection, cork bark, maritime industry, glue and similar products, graphics, ceramics, electric and electronic, rubber and tires recapping.

Showing increase maturity in the use of this flexible environmental policy instruments, the Portuguese Environmental Authority has been, during the last years, implementing a third generation Voluntary Approach: the Contracts for Continues Improvement of the Environmental Performance (CCIEP). These contracts are legally binding, as the EACs, but have the ambitious objective of pushing for over-compliance.

In the different Portuguese experiences with VAs we can identify two characteristics that are common to all of them:

- first the voluntary nature of the voluntary programs is respected, the firms have the choice to participate or not to participate, in particular in the case of the EAA or EACs, the firms face a menu of environmental policies where they can chose from accepting a direct regulation imposition or they adopt a VAs scheme;
- second in every experience the negotiation that precedes the implementation of the VA is between a representative of the public regulator and a representative of the group of firms.
- third the objective of all agreements is to improve the Portuguese environmental quality, considering specific benefits for the firms that decide to participate in the voluntary programs.

Through these characteristics we can confirm the existence of the collective action phenomenon supporting the implementation o the VAs.

III. VAs as a collective action: Theoretical background

The studies on Voluntary Approaches as a collective action phenomenon are supported on three main theoretical development:

- The fundamental work by Mancur Olson (1977), "The Logic of Collective Action", latter formalised and by T. Sandler (1992);
- The theoretical support from the oligopoly theory and the studies on cartel formation (d'Aspermont, Jacquemin and Gabszewicz, 1983), and "game theory"[2] and the more recent developments on the specific field of coalitions[3].
- The developments achieved in the study of the International Environmental Agreements and the collusive behaviour the supports them, with main contributes by Carraro e Siniscalco (1993, 1994) and Barrett (1994, 2003);

From the first reference, the concepts and prepositions proposed by Olson can be applied to the analyses of "collective action" under the framework of VAs.

As a first central concept, the definition of collective action as a phenomenon where a group of private agents create a good that has characteristics of a imperfect public good.

Then the distinctions between privilege, intermediate and latent groups (Olson, 1977, page 50):

> "A 'privilege' group is group such that each of its members, or at least some one of them, has an incentive to see that the collective good is provided, even if he has to bear the full burden o providing it himself. In such a group there is the presumption that the collective good will be obtained, and it may be obtained without any group organization or coordination whatever."
>
> "An 'intermediate' group is a group in which no single member gets a share of the benefit sufficient to give him an incentive to provide the good himself, but which does not have so many members that no one member will notice that any other member is or is not helping to provide the collective good. In such a group a collective good may, or equally well may not, be obtained, but no collective group may ever be obtained without some group coordination or organization."
>
> "A latent group "is distinguished by the fact that, if one member does or does not help provide the collective good no other one member will be significantly affected and therefore none has any reason to react"

Sandler summarises the Olson book in three themes (Sandler, 1992, pag 8 and 9):

[2] Dixit and Skeath, (1999) develop the instruments to formalize collective games.
[3] Carraro and Marchiori (2002) for a survey.

"1. Group size is, in part, a root cause of collective failure.
   a) Large groups may not provide themselves with a collective good; hence, no individual or coalition within the group may satisfy the sufficient condition of a privilege group.
   b) The larger the group, ceteris paribus, the greater the departure of the individual uncoordinated behaviour (also known as independent adjustment) from optimality; that is, the more suboptimal is the equilibrium.
   c) The larger the group, the smaller the collective provision level."

"2. Group asymmetry, in terms of individuals' tastes and/or endowments is related to collective failure.
   a) Larger members (dowse with greater endowments) will bear a disproportionate burden of collective provision 'there is a systematic tendency for the exploitation of the great by the small' (Olson, 1995, 35).
   b) Asymmetric groups are more likely o be privilege."

"3. Collective failure may be overcome through selective incentives (giving private benefit inducements) and institutional design."

The second and third theoretical references established the framework for the studies of VAs with two main contributions: the definition of the game structure that supports the environmental agreement; and the definition of the equilibrium concept that should be applied to such games.

In relation to the game structure, the international agreements analysed by Carraro e Siniscalco (1993, 1994) and Barrett (1994, 2003) are presented as the conclusion of a "metagame" played by different homogeneous countries in two stages: a first non-cooperative stage where all the players decide if they want to participate or not in the agreements; and a second stage where the participating players decide cooperatively the individual intervention taking into account the non-cooperative action of the non participates.

Dixit and Olson (2000) confirm this game structure as the most suitable for the study of "voluntary" participation of private agents in a collective agreement. They specifically call the attention for the necessity to consider a first stage of the game where the participants are asked if they are willing to participate or not, this is the stage where the voluntary nature of participation is tested; in the second stage the participants decide what will be de result of the agreements (has in the "international agreements" Dixit and Olson establish a "cooperative game of Caseian bargaining")

The equilibrium conditions in these games are deeply influenced by the oligopoly literature and the stability rules establishes for cartel formation (D'Aspermont,

Jacquemin and Gabszewicz, 1983), applied by Carraro and Siniscalco (1993) and Barrett, (1994) to the study of international agreements.

Segerson and Dawson (2000, pág. 13 and 14) summarized these equilibrium conditions into 4 conditions that we organise into requisites of rationality and stability:

Rationality:

R.1. "All participating firms are behaving optimally, given their decision to participate";

R.2. "All non-participating firms are behaving optimally, given their decision not to participate";

Stability

R.3. Internal Stability: "no participating firm has an incentive to become a non-participating firm";

R.4. External Stability: "no non-participating firm has an incentive to become a participating firm".

To translate these stability rules from "international agreements" theory to the voluntary approaches models, it is important to have in mind that the framework where the international agreements are constructed are different in many, significant, ways from the one where the negotiations between private firms take place (Segerson and Dawson, 2000 (a)).

- The environmental agreements are employed in the international negotiation as a response to the lack of an institutional framework and the inexistence of a legal entity capable of coercively controlling the action of the different countries.

  In the internal environmental policy the VAs act as an alternative to other regulation instruments.
- There is also a fundamental difference in the nature of the public good created for the active participants as a result of the collective action process. In the international agreement this public good is the global environmental improvements achieved. In the private VAs the firms that collude create a positive environmental impact but take advantage of other type benefits that are related to the voluntary action.

Given this two differences the importance of the stability conditions is maintained because, even though there is a clear institutional framework for internal environmental policy, the "voluntary nature" of the VAs and the fact that the benefits that are created

also assume characteristics of non-exclusivity and non-egoistic consumption the door to free-riding is open.

Following these different theoretical references, the study of the relation between voluntary approaches in environmental policy and collective action has been developed in two directions:

- in one direction, the collision phenomenon is not the central object of analysis but is recognized as existing and is a important element in the VAs implementation - papers by Maxwell, Lyon and Hackett, 2000; Millock and Salanié, 2000;
- a second type of analysis, where the study of the "collective action" process goes further and the objective is placed in identifying the incentives for collusion, with papers by Segerson and Dawson, 2000 and 2002; and Brau, Carraro and Golfetto, 2001.

IV. Basic model: the environmental regulation game

We consider a regulator (R) that is implementing an environmental policy through a menu of instruments from which the firms that belong to a specific polluting industry can choose.

The environmental policy menu is composed by:

- A "command and control" regulation measure where it is established a pollution restriction e_q and a fine T for non compliance.
- A Voluntary Approached program (VA) with a pollution objective e_V, $e_v < e_q$.

The polluting industry, focus of this environmental measure, is composed by N = 1 … n firms of two types, $\iota = \{L, H\}$, with $N_L = 1 \ldots l$ firms of type L and $N_H = 1 \ldots h$ firms of type H.

We consider:

$c(e,\theta_\iota) \rightarrow$ the abatement cost for a representative type ι firm, with $c(e,\theta_L)<c(e,\theta_H)$

$e_i \rightarrow$ Pollution level of firm i ($\bar{e} \rightarrow$ initial pollution)

$\theta \rightarrow$ random variable, reflects the difficulty in reducing the emissions

$c_e(e, \theta) \leq 0$; $c_{ee}(e,\theta) \geq 0$

$c_\theta(e,\theta) \geq 0$; $c_{e\theta}(e,\theta) \geq 0$

Give the policy menu:

$e_q \rightarrow$ pollution restriction, $e_q < \bar{e} \Rightarrow c(e_q,\theta_\iota) > c(\bar{e},\theta_\iota)$

$T \geq c(e_q,\theta_\iota)$

$e_v < e_q \Rightarrow c(e_v,\theta_\iota) > c(e_q,\theta_\iota)$

and let $\Delta(\theta_\iota) = c(e_v,\theta_\iota) - c(e_q,\theta_\iota) > 0$

The existence of a VA allows the firms to profit from a "spillover" effect with a positive financial outcome $z(\cdot)$ per firms that chooses to participate.

This spillover is a function of one or a combination of the three "environmental voluntary action benefits" (Brau, Carraro and Golfetto, 2000):

$z(e_v) = f_i(RC(e_v), CS(e_v), RE(e_v)) \rightarrow$ benefit per participating firm

- RC(e): regulatory capture, pre-emption or flexibilization
- CS(e): Cost Sharing, or R&D joint venture
- RE(e): Reputation enhancing with positive impact on commercial performance

Let b_ι be the benefit that a player gets from the participation of a firms type ι, and K_ι is the number of players of type ι that chose to participate.

The "imperfect public good" characteristics of this benefit allows for non participating firms to partially profit from it.

$\beta \rightarrow$ parameterises the "spillover" effect for "non agreeing firms".

$\beta = 1 \rightarrow$ "Spillover" has perfect public good characteristics

$0 < \beta < 1 \rightarrow$ "Spillover" has imperfect public good characteristics

The spillover benefit to each firm will be:

To firms that Participate= $(b_H \cdot K_H + b_L \cdot K_L) \cdot z(e_v)$

To firms that don't Participate = $\beta \cdot (b_H \cdot K_H + b_L \cdot K_L) \cdot z(e_v)$

We view the implementation of this environmental policy menu in an environmental regulation game with by stages:

1st Stage	2nd Stage	3rd Stage	4th Stage
Regulator proposes to the firms a VA as an alternative to a direct regulation instrument	The firms decide non-cooperatively to Participate (P) or not to participate (NP)	The firms decide the abetment level (effort)	The regulator verifies and executes the penalties if necessary

Where stages two and three correspond to the regulation game considered in the background literature and the initial and final stages are two support moments to the implementation of the environmental policy (which will not constitute an object of analyses in this introductory paper).

For the development of our model we consider the following simplifying assumptions:

A.I. The decision to establish a regulation menu is already taken and the structure of the menu is established.

A.II. The regulator has total capacity to enforce.

A.III. The VA is legally non-compulsory, for that the participation is completely free in the decision to participate or not to participate.

A.IV. All the firms that operate in the market are integrated in the same industrial association.

A.V. The market works under perfect competition.

As a consequence of assumptions A.II. and A.III the VA must be structured to be self-enforcing, which implies the simultaneous observation of requisites of rationality and stability (Segerson and Dawson, 2000, pág. 13 and 14):

Rationality:

R.1. "All participating firms are behaving optimally, given their decision to participate";

R.2. "All non-participating firms are behaving optimally, given their decision not to participate";

Stability

R.3. Internal Stability: "no participating firm has an incentive to become a non-participating firm";

R.4. External Stability: "no non-participating firm has an incentive to become a participating firm".

We can now establish that in any equilibrium that satisfies R1 and R2, maintaining the assumption A.II. and taking into consideration that $T > c(e_q,\theta_\iota)$ and $c_e(e, \theta) \leq 0$, any firm of type ι:

- that on the 3rd stage of the game chooses not to participate will always adopt pollution level e_q regardless of its type; and those firms that,

- on the 2nd stage, choose to participate will have to chooses e_V, which is in accordance to a "collective rationality" posture.

Considering this restrictions, each firm face on the 2nd stage a choice between:

To participate (P) which implies a pollution e_v with a cost of

$$C_P = c(e_v,\theta_\iota) - (b_H \cdot K_H + b_L \cdot K_L) \cdot z(e_v)$$

Not to participate (NP) which implies a pollution e_q with a cost of

$$C_{NP} = c(e_q,\theta_\iota) - \beta \cdot (b_H \cdot K_H + b_L \cdot K_L) \cdot z(e_v)$$

Once presented the baseline model we will star by considering a basic two heterogeneous players game (V), and then we will developed a grand game with the n players (VI), our objective is to identify what king of game structures will emerge from this regulation game, and what are the conditions for equilibrium.

V. Game with two players

Consider an environmental regulation game with two players: a player H (type θ_H) and player L (type θ_L).

It is possible to explore the payments of such a game using a simple normal form representation of a simultaneous one shot game (in each cell the payment on top will be the one of the row player and the one on the bottom the payment of the column player):

		H	
		Participating	Not Participating
L	Participating	$c(e_v,\theta_L) - (b_H + b_L)\cdot z(e_v)$ $c(e_v,\theta_H) - (b_H + b_L)\cdot z(e_v)$	$c(e_v,\theta_L) - b_L \cdot z(e_v)$ $c(e_q,\theta_H) - \beta \cdot b_L \cdot z(e_v)$
	Not Participating	$c(e_q,\theta_L) - \beta \cdot b_H \cdot z(e_v)$ $c(e_v,\theta_H) - b_H \cdot z(e_v)$	$c(e_q,\theta_L)$ $c(e_q,\theta_H)$

The equilibrium strategies of each one of the players depend on the relation between:

- $\Delta(\theta_\iota) = c(e_v,\theta_\iota) - c(e_q,\theta_\iota) > 0 \rightarrow$ increase in abatement costs associated with participating
- $b_\iota \cdot z(e_v) \rightarrow$ spillover benefit that player ι brigs to the VA if it participates
- $(1-\beta) \cdot b_\varphi \cdot z(e_v) \rightarrow$ percentage of spillover created by the participation of player φ that player ι benefits if he decides to participate ($\varphi \neq \iota$),

- $(1-\beta)\cdot b_{\varphi}\cdot z(e_v) + b_{\iota}\cdot z(e_v) \rightarrow$ is the spill-hover benefit for player ι if he decides to participate together with player φ.

We will find strictly dominate strategies in the following situations (considering two players $\iota,\varphi \in \{L,H\}$ and $\iota \neq \varphi$):

(i) Participating is a strictly dominate strategy for player ι:

when player φ plays participate and the payment for player ι is so that:

$$\Delta(\theta_{\iota}) < (1-\beta)\cdot b_{\varphi}\cdot z(e_v) + b_{\iota}\cdot z(e_v), \text{ and}$$

when player φ plays non-participate the payment for player ι is so that:

$$\Delta(\theta_{\iota}) < b_{\iota}\cdot z(e_v)$$

It is possible to conclude:

Preposition 1.

With two players, types $\iota,\varphi \in \{L,H\}$ and $\iota \neq \varphi$, if

$$\Delta(\theta_{\iota}) < b_{\iota}\cdot z(e_v),$$

playing participation is a strictly dominant strategy for player ι.

Intuition: if the spillover benefit created by the firm is enough to cover the increase in cost the firm will support by participation, it will choose that strategy.

If both players are in this same situation we have a "Fully Privilege" (FP) game where firms are willing to coordinate themselves participating in the VA, i.e., in Olson terms, we will have a "fully privilege group".

Note: if $\beta = 1$, i.e., the spillover is a pure public good, the conditions will be reduced to

$$\Delta(\theta_{\iota}) < b_{\iota}\cdot z(e_v).$$

(ii) Non-Participating is a strictly dominate strategy for player ι:

when player φ plays participate the payment for player ι is so that:

$$\Delta(\theta_{\iota}) > (1-\beta)\cdot b_{\varphi}\cdot z(e_v) + b_{\iota}\cdot z(e_v), \text{ and}$$

when player φ plays non-participate the payment for player ι is so that:

$$\Delta(\theta_{\iota}) > b_{\iota}\cdot z(e_v)$$

Symmetrically in relation to the former situation, we can establish that:

Preposition 2:

With two players types $\iota,\varphi \in \{L,H\}$ and $\iota \neq \varphi$, if

$$\Delta(\theta_\iota) > (1-\beta)\cdot b_\varphi \cdot z(e_v) + b_\iota \cdot z(e_v),$$

playing non-participation is a strictly dominant strategy for player ι.

Intuition: when the spillover benefit created by the firm is not enough to cover the increase in cost the firm will support if it chooses to participate the firm will choose a strategy of non-participating.

If both players, simultaneously, have this dominant strategy we have a "Prisoner Dilemma" (PDG) game where firms are not willing to cooperate

Note: With $\beta = 1$, the conditions will be reduced to

$$\Delta(\theta_\iota) > b_\iota \cdot z(e_v).$$

Heterogeneity (perfect public good)

What types of games are created if we introduce the heterogeneities between the firms?

The strategies for each game are based in the relations between abatement cost differences and the spillover gains.

Comparing these values for the different types of firms:

$\Delta(\theta_H) = c(e_v,\theta_H) - c(e_q,\theta_H) \rightarrow$ increase in abatement costs associated to participating for firm type H

$\Delta(\theta_L) = c(e_v,\theta_L) - c(e_q,\theta_L) \rightarrow$ increase in abatement costs associated to participating for firm type L

Being e_q and e_v the same for all firms regardless of its type, and because: $c_e(e, \theta) \leq 0$; $c_{ee}(e,\theta) \geq 0$; $c_\theta(e,\theta) \geq 0$; $c_{e\theta}(e,\theta) \geq 0$, the total abatement cost function of the H type firm will always be steeper and so:

$$\Delta(\theta_H) > \Delta(\theta_L)$$

In relation to the contribution of each type of firm to the spill-over, we can encounter three different situations.

(A) $b_H = b_L = b$, i.e., if the contribution is independent of the type of the firm.

(B) $b_H > b_L$, i.e., if the contribution from firm H to the spillover effect is higher than the one produced by the participation of L is independent of the type of the firm.

(C) $b_H < b_L$, i.e., if the contribution from firm L is higher than the one produced by H.

In a first approach lets consider that the spillover has characteristics of a perfect public good, and so $\beta = 1$.

As we saw, in this situation the strictly dominant strategy of the firm ι is:

to Participate if → $\Delta(\theta_\iota) < b_\iota \cdot z(e_v)$

to Not-Participate if → $\Delta(\theta_\iota) > b_\iota \cdot z(e_v)$

The normal form generic game will be: poet

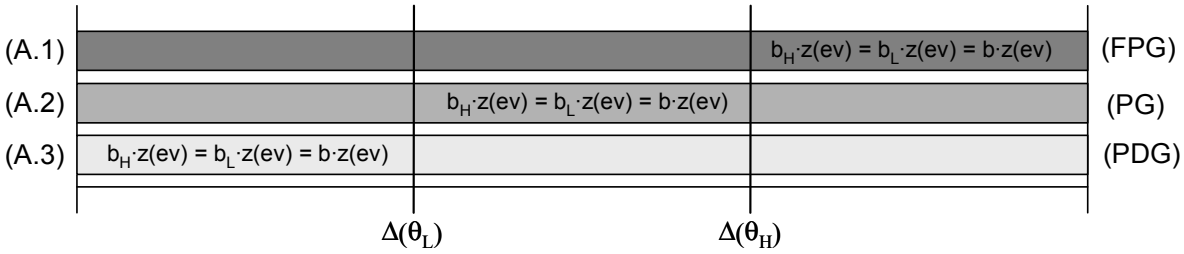
		H	
		Participating	Not Participating
L	Participating	$C(e_v,\theta_L) - (b_H + b_L)\cdot z(e_v)$ $c(e_v,\theta_H) - (b_H + b_L)\cdot z(e_v)$	$c(e_v,\theta_L) - b_L \cdot z(e_v)$ $c(e_q,\theta_H) - b_L \cdot z(e_v)$
	Not Participating	$c(e_q,\theta_L) - b_H \cdot z(e_v)$ $c(e_v,\theta_H) - b_H \cdot z(e_v)$	$c(e_q,\theta_L)$ $c(e_q,\theta_H)$

(A) $b_H = b_L = b$

If the contribution to the spillover is the same regardless of the firm type, the following equality also holds:

$$b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v)$$

We must now analyze three different possibilities:



(A.1.) "Fully Privileged Game" (FPG)

In this case we have:

$$\Delta(\theta_H) > \Delta(\theta_L) > b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v)$$

Participating is a dominant strategy for both players (figure 1).

The equilibrium of this game is a natural cooperation between players.

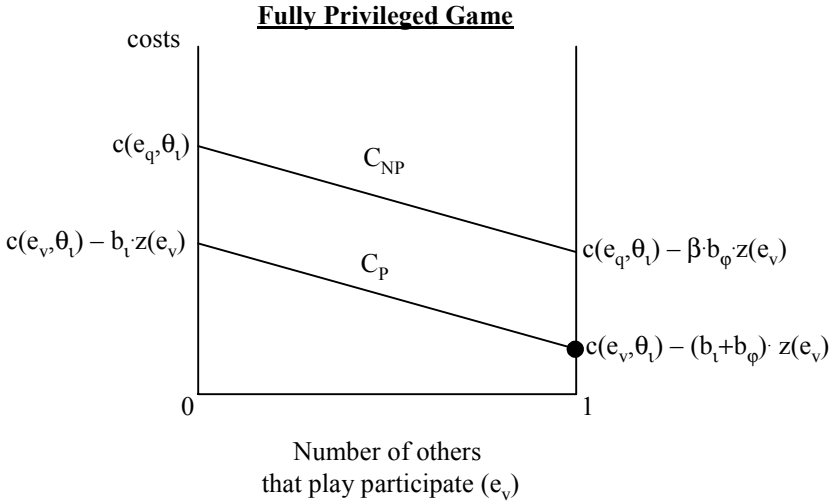


Figure 1.

(A.3.) "Prisoner Dilemma Game" (PDG)

In the opposite situation:

$$b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v) < \Delta(\theta_L) < \Delta(\theta_H)$$

Non participating is a dominant strategy, and non of the firms will sign the VA. (Figure 2.)

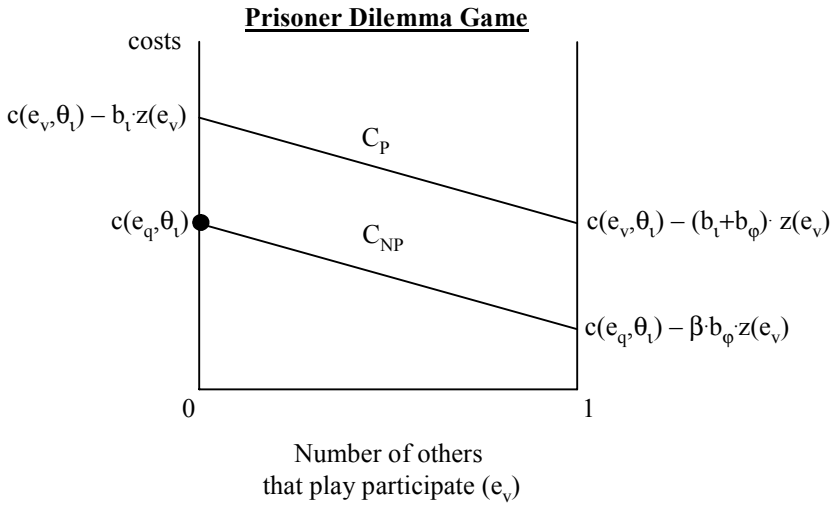


Figure 2.

(A.2.) "Privileged Game" (PG)

Following the concepts presented by Olson (1977) we use the term "fully privilege" (as Sandler, 1992) to refer to groups where both players have an incentive to participate in the VA and so cooperation is inevitable. The term

"privilege" will be used when the "collective good" is also provided but only one of the firms has the incentive to participate in the VA.

In this intermediate situation,

$$\Delta(\theta_L) < b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v) < \Delta(\theta_H)$$

we find that the benefits created with the VA are enough to induce the participation o a firm type L but not firm type H and so we have "privilege games" (Figure 3.).

In this scenery firms type H will free ride, taking advantage of the "spill-over" created by firm L.

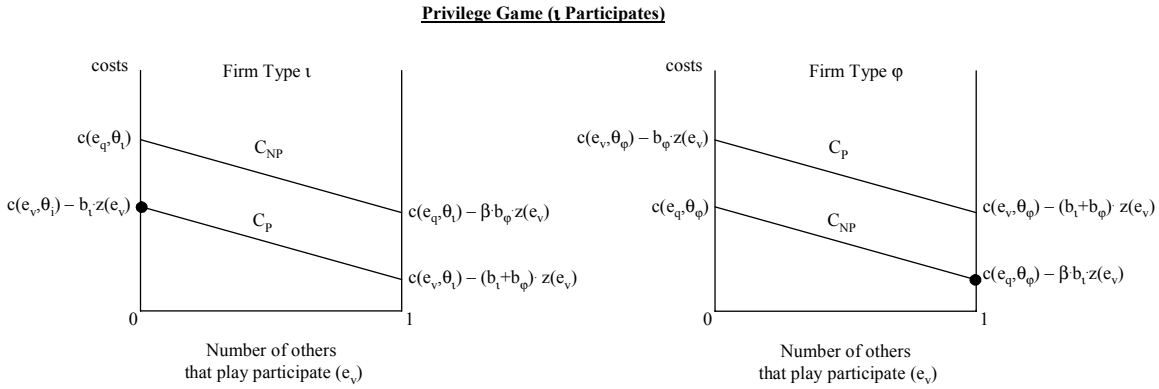
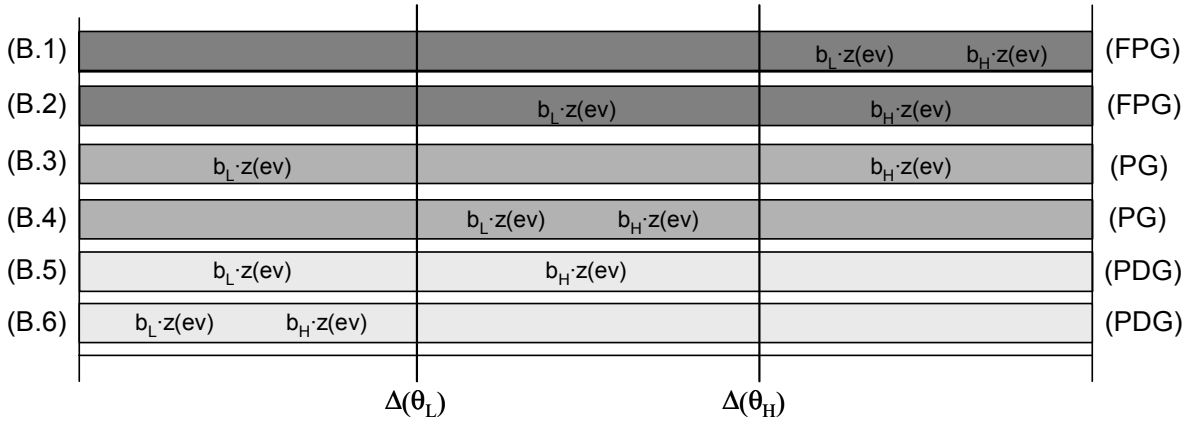


Figure 3.

(B) $b_H > b_L$

Even though the sceneries that are now possible are 5, the conclusions are very similar to the former analyses:



- Situation (B.1) and (B.2) replicate the conclusions of (A.1) → (FPG)

- Situation (B.5) and (B.6) replicate the conclusions of (A.3) → (PDG)
- Situation (B.4) is the same as (A.2), → (PG)
- The situation (B.3) introduces the novelty, where a new "privilege game" gives the possibility to L to "free ride" → (PG)

(C) $b_L > b_H$

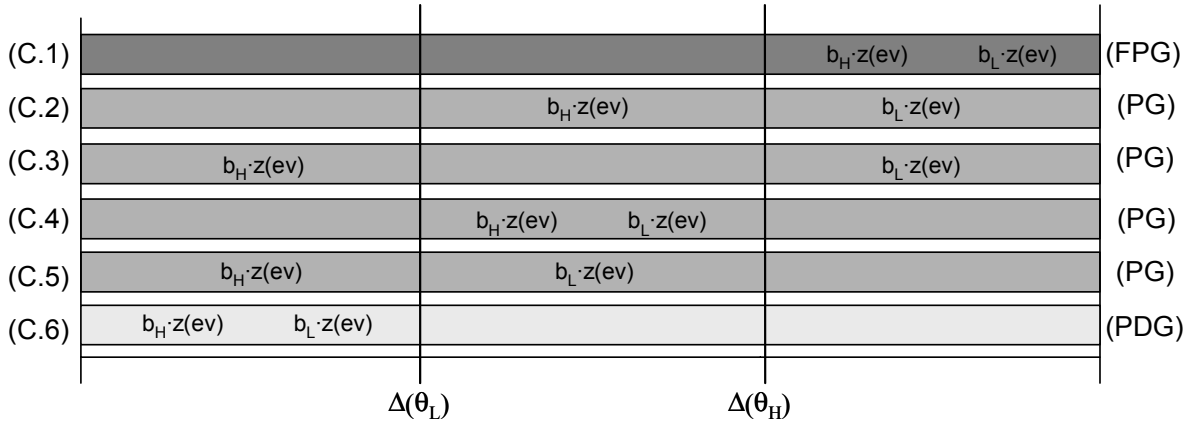
In this last situation, the possibilities of H to practice free-riding increase.

Sceneries:

- (C.1) is equivalent to (A.1) → (FPG)
- (C.6) is equivalent to (A.3) → (PDG)
- (C.4) is equivalent to (A.2) → (PG)

But now (C.2), (C.3) and (C.5) also represent "Privileged games", where we find, again, a situation where firm type L has an incentive to participate wile firm H "free-rides".

Note, that in relation to the situation where $b_H > b_L$, L loses the chance to free-ride.



From these developments it is ease to reach the following generalizations:

Preposition 3:

If non participating is a strictly dominant strategy for the firm Type L, it is also a strictly dominant strategy for a firm type H.

Preposition 4:

If participating is a strictly dominant strategy for the firm Type H, it is also a strictly dominant strategy for a firm type L.

Heterogeneity (imperfect public good)

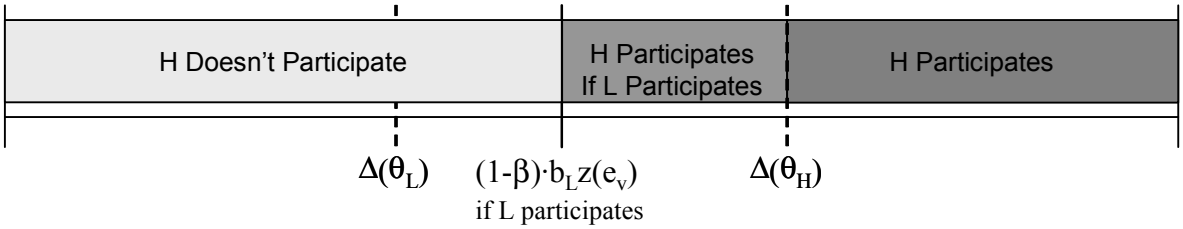
If we let $0<\beta<1$, the cost of not participating in the AV increases by $(1-\beta)\cdot b_{\varphi}\cdot z(e_v)$ for each player ι ($\iota,\varphi\in\{L,H\}$ and $\iota\neq\varphi$) whenever player φ participates.

Through preposition 1, we can establish that the decision to Participate in a VA, for any firm ι, is only changed when $\Delta(\theta_\iota) > b_\iota\cdot z(e_v)$ and φ participates.

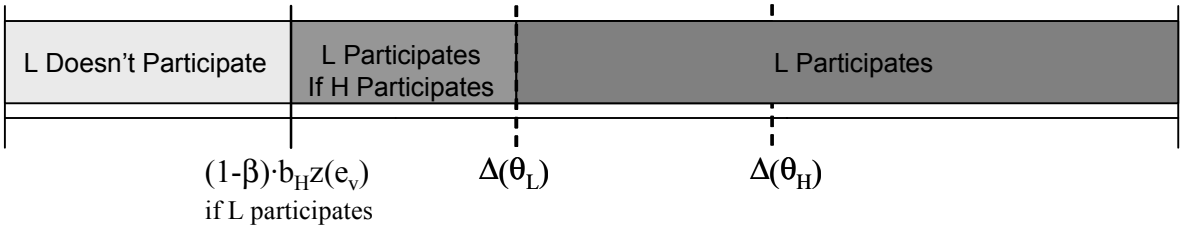
For the cases where $\Delta(\theta_\iota) < b_\iota\cdot z(e_v)$ the conclusions attained for the pure public good case are sustained.

Actually, in relation to the analyses we made, the transformation is that the limiting value to decide not to participate decreases by $(1-\beta)\cdot b_{\varphi}\cdot z(e_v)$ for each player ι whenever player φ plays Participate ($\iota,\varphi\in\{L,H\}$ and $\iota\neq\varphi$).

For player H, and values of $b_H\cdot z(e_v)$



For player L, and values of $b_L\cdot z(e_v)$



Given these conditions, in relation the previous sceneries, there are three main changes:

(1) The reinforcement of the "fully privilege" situations:

Supported by the guarantied participation of L, the FPG (A.1), (B.1), (B.2) and (C.1), increase there space of equilibrium values given that player H increases it's interest to participate by the value $(1-\beta)\cdot b_L\cdot z(e_v)$.

(2) The transformation of "privilege" situations it to "fully privilege".

In sceneries (A.2), (B.4), (C.2), (C.3), (C.4), (C.5), being that L participates, H can be persuade to droop the free-riding option if the value $(1-\beta)\cdot b_L\cdot z(e_v)$ justifies it.

In the scenery (B.3), L can be persuaded to participate if the value $(1-\beta)\cdot b_H\cdot z(e_v)$ created by the participation of H, also, justifies it.

(3) The transformation of the "Prisoner Dilemma Games" it to "Intermediate Group Games" (IGG))

We consider a "Intermediate Group Games" to be a game where the participation in the VA demands a coordination between players. The payments of the game are such that there are two equilibriums in pure strategies in which booth Participate or Don't Participate (Figure 4).

In game theory this are "pure coordination games", the name ""Intermediate Group Games" follow the concept of "intermediate groups" presented by Olson, where the "collective good" is provided only if there is a coordination between the agents.

Intermediate Group Games
(Pure coordination game)

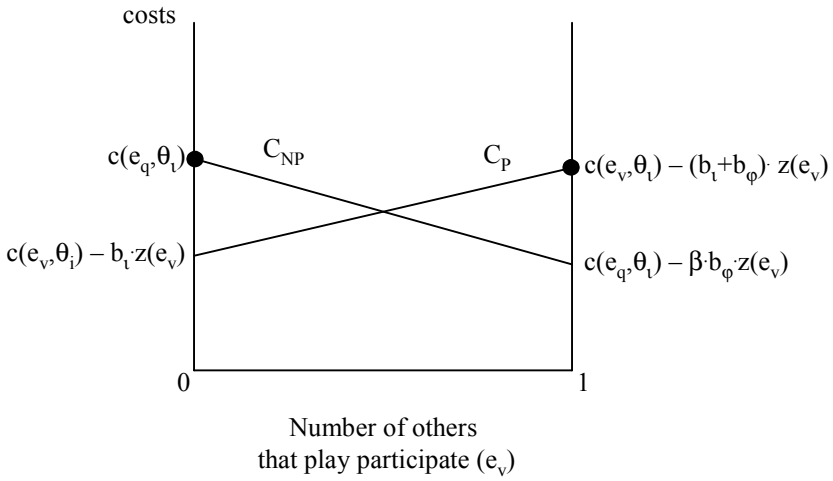


Figure 4.

For such it is necessary that, for each player $\iota,\varphi \in \{L,H\}$ and $\iota \neq \varphi$:

When player φ plays participate the payment for player ι is so that:

$$\Delta(\theta_\iota) < (1-\beta)\cdot b_\varphi \cdot z(e_v) + b_\iota \cdot z(e_v), \text{ and}$$

When player φ plays non-participate the payment for player ι is so that:

$$\Delta(\theta_\iota) > b_\iota \cdot z(e_v)$$

Intuition:

- When the player is alone the benefits that he creates are not enough to justify the cost of participating.

- With the entrance of the other player, if the spillover is not a perfect public good, the gains from participating together will be justified[4]

When the "spill-over" is no longer a perfect public good the PDG can be transformed into a Coordination Games, depending on the relative values of $\Delta(\theta_\iota)$ and the importance of the "spill-over".

IV. Game with n players

We are now considering the extension game with N players, where:

$$N = N_H + N_L$$

and N_ι is the number of players of type ι, $\iota = \{L, H\}$.

K will be the total number of firms that decide to participate, and:

$$K = K_H + K_L$$

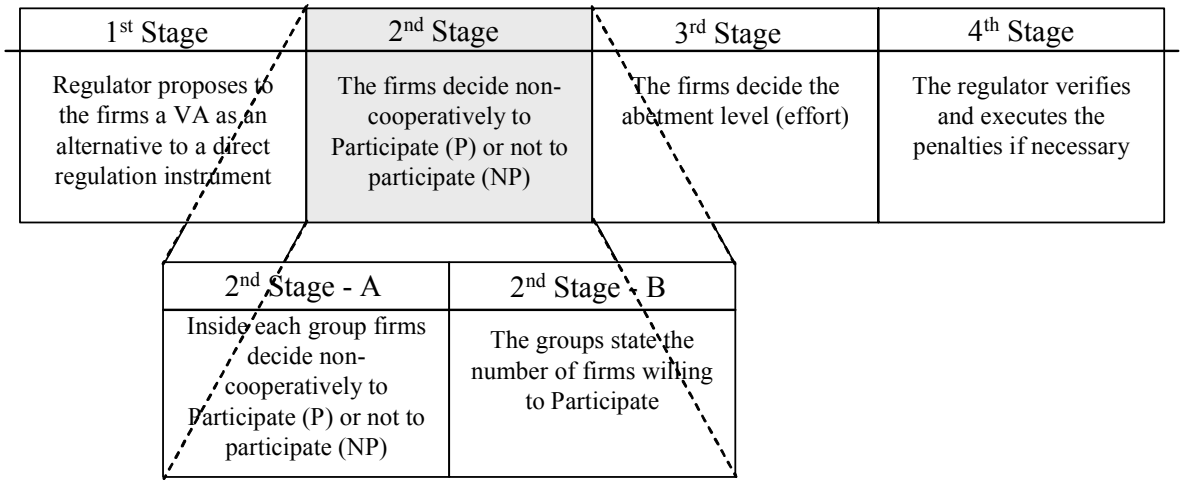
where K_ι is the number of players of type ι that participates , $\iota = \{L, H\}$.

We already establish that, for a firm type ι, the cost:

when it decides to participate → $C_P = c(e_v,\theta_\iota) - (b_H \cdot K_H + b_L \cdot K_L) \cdot z(e_v)$

when it decides not to participate → $C_{NP} = c(e_q,\theta_\iota) - \beta \cdot (b_H \cdot K_H + b_L \cdot K_L) \cdot z(e_v)$

To better understand the decision the firms are now facing the structure of the game can be slightly modified with an extended 2nd stage:



[4] Interesting to note that if the spillover is a pure public good (β=1) we can not have a pure coordination game.

We will consider that the firms are organized in homogeneous groups depending in their types'.

The decision to Participate or Not to Participate is non-cooperative inside each group and in relation to the firms in the other group.

After they reach a equilibrium inside of the group, the number of participants from each group is stated, and a global equilibrium is accessed

In comparison to the development of the two players' game there are two important differences:

1st. The stability conditions of the self-enforcing equilibrium are now of central importance in the equilibrium of the n games

2nd The action inside each croup, after the decision to participate is taken, is characterised by "collective rationality" principle.

The literature normally associates the different stages of an n player game with different arrangements between the players.

Following Barrett (1994), it is assumed that, "signatories maximize there collective net benefits, recognizing how their choice of the treaty obligations affects the actions of non-signatories, while non-signatories each choose their action on the assumption that other countries will not respond."

Applying this assumption to our terminology (as Dixit and Olson, 2000), after the second stage, the players participating in the VA act cooperatively between themselves and those that don't participate act non-cooperatively, i.e., it is assumed "collective rationality" on the part of the *treaty signatories*" (Barrett, 2003, page 197)

The cost structure of a marginal firm ι belonging to a group type ι

Take a firm type ι that belongs to a group of N_ι firms that must decide between participating or not to participate in a VA assuming that K_ι firms of type ι as well as K_φ firms of type φ decided to participate (considering N_ι and N_φ players type $\iota,\varphi \in \{L,H\}$ and $\iota \neq \varphi$).

The payments for this firm type ι are established following the stability function presented by Carraro and Marchiori (2002)[5].

[5] Applied in collective games, see Dixit and Skeath, 1999.

To participate (P) implies a pollution e_v with a cost of

$$C_{P(K\varphi)} = c_i(e_v,\theta_\iota) - [b_\iota\cdot(K_\iota+1)+ b_\varphi\cdot K_\varphi] \cdot z(e_v)$$

Not to participate (NP) implies a pollution e_q with a cost of

$$C_{NP(K\varphi)} = c_i(e_q,\theta_\iota) - \beta \cdot (b_\iota\cdot(K_\iota) + b_\varphi\cdot K_\varphi) \cdot z_i(e_v)$$

Considering that there are N_ι firms of type ι the figure 5 represents the impact of the marginal firm ι decision in relation with the decision of the other N_ι firms.

From this graphic we can retrieve the following information from the graphic (at this moment we will not paying attention to the particular equilibrium that is represented):

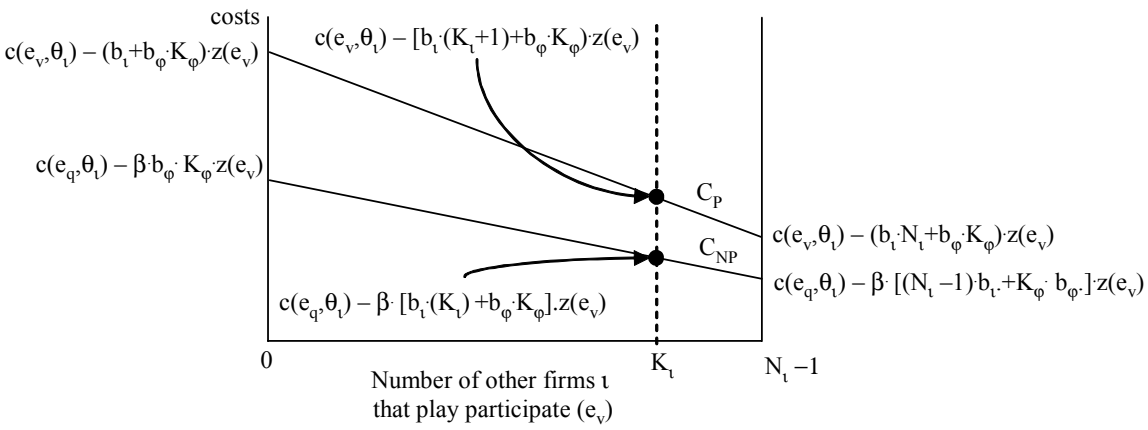


Figure 5

- Both functions are decreasing linearly with the number of firms type ι that decide to participate: $C_{P(K\varphi)}$ decreases at a rate $b_\iota\cdot z(e_v)$, $C_{NP(K\varphi)}$ decreases at a rate $\beta\cdot b_\iota\cdot z(e_v)$.
- Assuming the participation of K_ι firms, the difference between $C_{P(K\varphi)}$ and $C_{NP(K\varphi)}$ is due to the following values:
  i. $\Delta(\theta_\iota) = c(e_v,\theta_\iota)-c(e_q,\theta_\iota) \rightarrow$ the difference in abatement costs associated with participating, with $\Delta(\theta_\iota) > 0$;
  ii. $(1-\beta)\cdot b_\varphi\cdot K_\varphi\cdot z(e_v) \rightarrow$ percentage of spillover created by the participation of players type φ that player ι benefits if he decides to participate ($\varphi\neq\iota$). Under the assumption that there are K_φ firms participating, this is a fixed value
  iii. $(1-\beta)\cdot K_\iota\cdot b_\iota\cdot z(e_v) \rightarrow$ spillover benefit that players type ι brigs to the VA if it participates, due to β the $C_{NP(K\varphi)}$ decreases at a slower rate than C_P when $\beta\in(0,1)$ (i.e., not a pure public good)

$$\frac{\partial C_P}{\partial K_\iota} = -b_\iota \cdot z(e_v) \text{ and } \frac{\partial C_{NP}}{\partial K_\iota} = -\beta \cdot b_\iota \cdot z(e_v)$$

Note: if $C_{NP(K\varphi)} > C_{P(K\varphi)}$ for $K_\iota = 0$ then de difference between $C_{P(K\varphi)}$ and $C_{NP(K\varphi)}$ increases with K_ι;

if $C_{NP(K\varphi)} < C_{P(K\varphi)}$ for $K_\iota = 0$ then de difference between C_P and C_{NP} decreases with K_ι

iv. $\beta \cdot b_\iota \cdot z(e_v) \rightarrow$ Value related to the participation of firm ι that corrects the value $(1-\beta) \cdot K_\iota \cdot b_\iota \cdot z(e_v)$.

The interaction between two marginal firms ι and φ

Take two marginal firms, ι of type ι and φ of type φ (considering N_ι and N_φ players type $\iota,\varphi \in \{L,H\}$ and $\iota \neq \varphi$)

These two marginal firms must decide to participate or not in the VA.

The normal form of a game between these two firms is: (following a development similar to the one used in Carraro e Siniscalco 1993,),

		(marginal) Firm type φ	
		Participating	Not Participating
ι	Participating	$c(e_v,\theta_\iota) - [b_\iota \cdot (K_\iota+1) + b_\varphi \cdot (K_\varphi+1)] \cdot z(e_v)$ $c(e_v,\theta_\varphi) - [b_\iota \cdot (K_\iota+1) + b_\varphi \cdot (K_\varphi+1)] \cdot z(e_v)$	$c(e_v,\theta_\iota) - [b_\iota \cdot (K_\iota+1) + b_\varphi \cdot K_\varphi] \cdot z(e_v)$ $c(e_q,\theta_\varphi) - \beta \cdot [b_\iota \cdot (K_\iota+1) + b_\varphi \cdot K_\varphi] \cdot z(e_v)$
	Not Participating	$c(e_q,\theta_\iota) - \beta \cdot [b_\iota \cdot K_\iota + b_\varphi \cdot (K_\varphi+1)] \cdot z(e_v)$ $c(e_v,\theta_\varphi) - [b_\iota \cdot K_\iota + b_\varphi \cdot (K_\varphi+1)] \cdot z(e_v)$	$c(e_q,\theta_\iota) - \beta \cdot (b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi) \cdot z(e_v)$ $c(e_q,\theta_\varphi) - \beta \cdot (b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi) \cdot z(e_v)$

Following the same rezoning we used in the two players game, we will try to define the conditions under which we find dominant strategies for the marginal player type ι.

The definition of these conditions will take us to analyse graphics such as the one presented at figure 6.

In these graphics we find two pares of cost curves for firm ι:

- a set of curves representing the cost of participating ($C_{P(K\varphi)}$) or not participating ($C_{NP(K\varphi)}$) without the participation of the marginal firm type φ, i.e., admitting K_φ type φ participating firms,

- and a second set of curves ($C_{P(K\varphi+1)}$ and $C_{NP(K\varphi+1)}$) admitting that the φ decides to participate, i.e., with $K_\varphi+1$ type φ participating firms.

We see that the participation of the marginal φ firm represents a horizontal movement of each cost curve downwards.

It is important to note that this displacement depends on the value of β.

When $\beta \in (0,1)$ the C_P curve with fall down for $b_\varphi \cdot z(e_v)$ wile the C_{NP} curve will only fall down by $\beta \cdot b_\varphi \cdot z(e_v)$, i.e., the entrance of the marginal φ player will have an impact $(1-\beta)$ higher over the C_P cost curve that over the C_{NP}, so the relative position between the cost curve might change whenever the collective good is not a perfect public good.

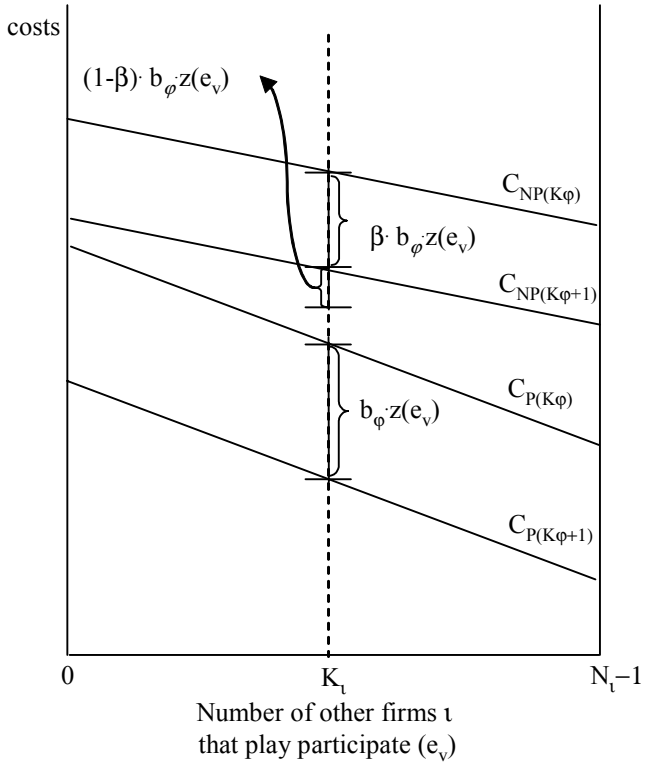


Figure 6.

(I) Participating is a strictly dominate strategy for player ι

To find a strictly dominant strategy in participation we now have to fulfil with the following conditions:

When φ plays non participation ι payoffs must be such as:

$$C_P(K_\varphi) < C_{NP}(K_\varphi) \Rightarrow \Delta(\theta_\iota) < b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

When φ plays participation ι payoffs must be such as:

$$C_P(K_{\varphi+1}) < C_{NP}(K_{\varphi+1}) \Rightarrow \Delta(\theta_\iota) < b_\iota \cdot z(e_v) + (1-\beta)\cdot b_\varphi \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

In both situations we are stating, as is perfectly intuitive, that firm ι will participate if the extra gain with the spillover compensates for the increase in cost.

The difference between these two conditions is in the extra gain that comes from the φ firm contribution to the spillover.

It is easy to see that the first condition is sufficient to guaranty that Participating is a strictly dominant strategy.

If we verify that

$$\Delta(\theta_\iota) < b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

each firm will choose to Participate as a dominant strategy because the excess cost it pays for participating ($\Delta(\theta_\iota)$) is less than the "extra benefit" it attains when Participating ($b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$).

To verify that this condition is sufficient we use figure 7, where we consider a situation where:

$$\Delta(\theta_\iota) = b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v) \Rightarrow C_P(K_\varphi) = C_P(K_\varphi) \text{ for } K_\iota$$

Admitting that, being indifferent firm ι would prefer to participate, with the entrance of a firm type φ it would be created a situation where $C_P(K_\varphi) = C_P(K_\varphi)$ for K_ι due to the characteristic discussed before.

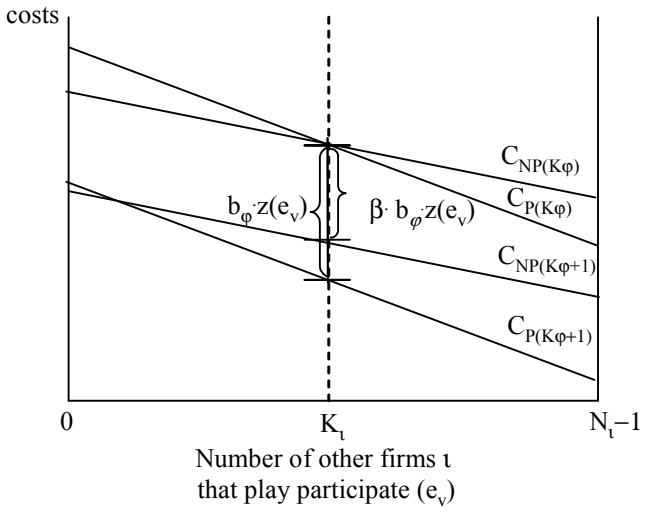


Figure 7.

Preposition 5:

In a n players game if $C_{NP(K\varphi)} > C_{P(K\varphi)}$ for $K_\iota = 0$, equilibrium will include the N_ι firms of type ι participating, regardless of the action of the firms type φ.

Prof:

1st if $C_{NP(K\varphi)} > C_{P(K\varphi)}$ for $K_\iota = 0$ then de difference between $C_{P(K\varphi)}$ and $C_{NP(K\varphi)}$ increases with K_ι;

2nd if $C_{NP(K\varphi)} > C_{P(K\varphi)}$ for $K_\iota = 0$ then participation of a additional firms type φ will not affect the relative position of the cost curves.

(II) Non-Participating is a strictly dominate strategy for player ι

To find a strictly dominant strategy in non-participation the following conditions must be fulfilled:

When φ plays non participation ι payoffs must be such as:

$$C_P(K_\varphi) > C_{NP}(K_\varphi) \Rightarrow \Delta(\theta_\iota) > b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

When φ plays participation ι payoffs must be such as:

$$C_P(K_{\varphi+1}) > C_{NP}(K_{\varphi+1}) \Rightarrow \Delta(\theta_\iota) > b_\iota \cdot z(e_v) + (1-\beta)\cdot b_\varphi \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

As before, we can prove that the verification of the second condition is enough to guaranty that non participation is a dominant strategy.

It is possible to give a second reading to the two sufficient conditions for dominant strategies:

Participating is a dominant strategy if:

$$\Delta(\theta_\iota) < b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

$$\Rightarrow \quad C_P(K_\varphi) - C_{NP}(K_\varphi) < 0$$

Non- Participating is a dominant strategy if:

$$\Delta(\theta_\iota) > b_\iota \cdot z(e_v) + (1-\beta)\cdot b_\varphi \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

$$\Rightarrow \quad \Delta(\theta_\iota) - b_\iota \cdot z(e_v) - (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v) > (1-\beta)\cdot b_\varphi \cdot z(e_v)$$

$$\Rightarrow \quad C_P(K_\varphi) - C_{NP}(K_\varphi) > (1-\beta)\cdot b_\varphi \cdot z(e_v)$$

Which means that the dominance of the non-participation strategy exists when the difference in costs between participating and non-participating, with K_ι and K_φ firms, is not compensated by the extra benefit created by the participation of the marginal φ firm.

Heterogeneity in the n player game with β = 1 (pure public good)

If the spillover has characteristics of a pure public good (β=1) the game is affected in tow important ways:

- the decision not to participate doesn't imply the lost of advantages created by the participating firms;
- the entrance of one marginal firm has exactly the same impact over the two cost curves (C_P and C_{NP}), i.e., in graphic terms the two curves move downwards by the same distance maintaining there relative position.

We continue to consider the existence N_L L type firms and N_K K type firms, from which K_L, L type firms and K_K, K type firms, choose to participate.
There are two marginal firms that face the decision to enter the VA (i.e., to Participate) or not to enter (i.e., Not to Participate): firm L, of type L, and firm H, of type H.

Considering the heterogeneity and that the spillover is a pure public good, the game in normal form is represented in the following way:

		(marginal) Firm type K	
		Participating	Not Participating
L	Participating	$c(e_v,\theta_L) - [b_L\cdot(K_L+1) + b_K\cdot(K_K+1)]\cdot z(e_v)$ $c(e_v,\theta_K) - [b_L\cdot(K_L+1) + b_K\cdot(K_K+1)]\cdot z(e_v)$	$c(e_v,\theta_L) - [b_L\cdot(K_L+1) + b_K\cdot K_K]\cdot z(e_v)$ $c(e_q,\theta_K) - [b_L\cdot(K_L+1) + b_K\cdot K_K]\cdot z(e_v)$
	Not Participating	$c(e_q,\theta_L) - [b_L\cdot K_L + b_K\cdot(K_K+1)]\cdot z(e_v)$ $c(e_v,\theta_K) - [b_L\cdot K_L + b_K\cdot(K_K+1)]\cdot z(e_v)$	$c(e_q,\theta_L) - (b_L\cdot K_L + b_K\cdot K_K)\cdot z(e_v)$ $c(e_q,\theta_K) - (b_L\cdot K_L + b_K\cdot K_K)\cdot z(e_v)$

From the analysis of the two player's game we already know that:

$$\Delta(\theta_H) > \Delta(\theta_L)$$

The sufficient conditions for strictly dominant strategies are:

- Participating is a strictly dominant strategy, if we verify

$$\Delta(\theta_\iota) < b_\iota\cdot z(e_v)$$

- Non-Participating is a strictly dominant strategy, if we verify

$$\Delta(\theta_\iota) > b_\iota\cdot z(e_v)$$

From the two sufficient conditions we can establish that: if the spillover is a pure public good, the decision to Participate or Not to Participate is independent of the number and the type of firms already participating in the VA.

Has before the conditions for equilibrium in the regulation games are dependent on the relation between b_H and b_L.

(A_n) $b_H = b_L = b$

If the contribution to the spillover is the same regardless of the firm type, the following equality also olds:

$$b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v)$$

We must now analyze three different possibilities:

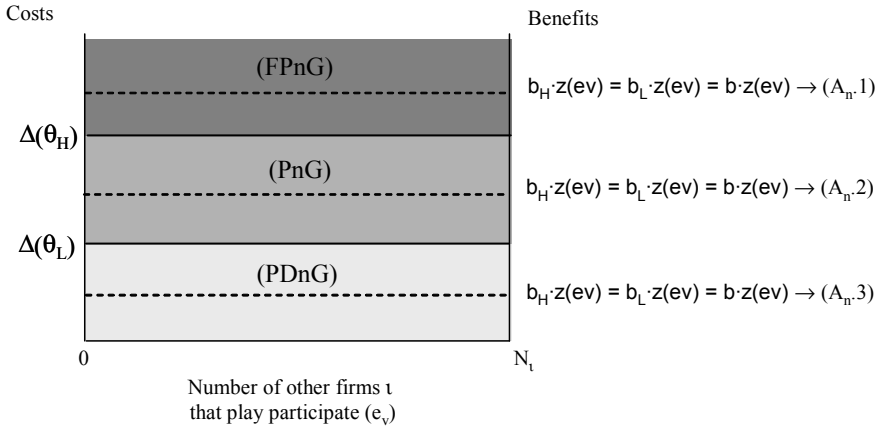


Figure 8

Figure 8, contains:

- two horizontal line, $\Delta(\theta_\iota)$, representing the excess cost firms L and H suffer for participating; the value $\Delta(\theta_\iota)$ is independent of the number of K_ι participating firms
- three possible "extra benefit function", $b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v)$, representing the extra benefit that each firm L an H attain when they decide to participate; this functions are no dependent on K_ι because $\beta = 1$.

(A_n.1.) "Fully Privileged n Game" (FPnG)

In this case we have:

$$\Delta(\theta_H) > \Delta(\theta_L) > b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v)$$

Participating is a dominant strategy for both marginal players.

The equilibrium of this game is the grand cooperation between players from the different types.

In graphical terms, each marginal firm would face a situation like the one expressed the figure 9.

$C_{NP(K\varphi)}$ is always higher than $C_{P(K\varphi)}$ whatever the number of firms from the same type participating.

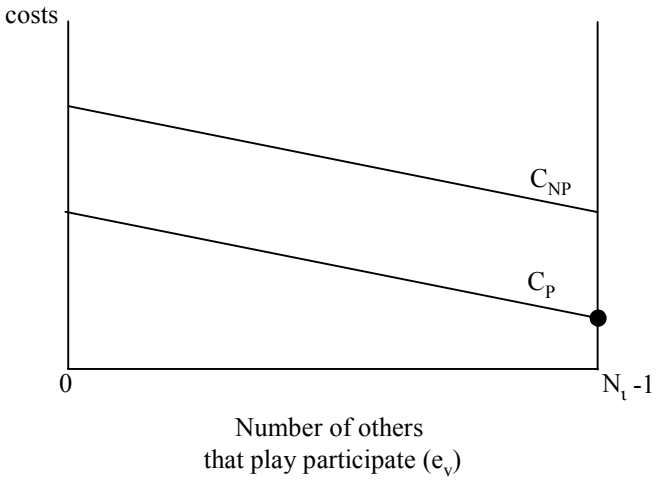


Figure 9

(A_n.3.) "Prisoner Dilemma n Game" (PDnG)

In the opposite situation:

$$b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v) < \Delta(\theta_L) < \Delta(\theta_H)$$

Non participating is a dominant strategy, and non of the firms will sign the VA (Figure 10) .

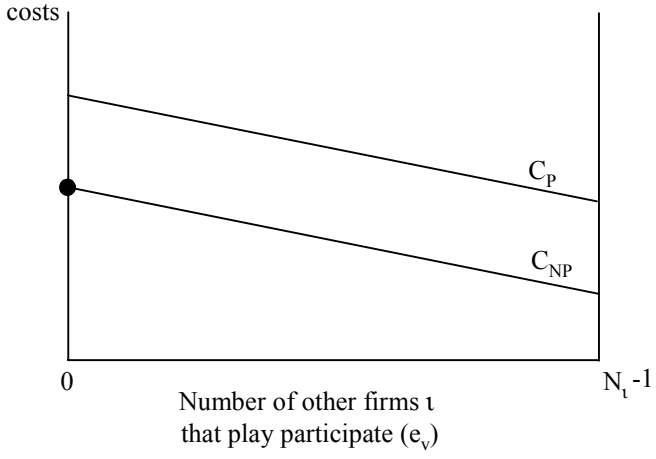


Figure 10

(A_n.2.) "Privileged n Game" (PnG)

In the intermediate situation,

$$\Delta(\theta_L) < b_H \cdot z(e_v) = b_L \cdot z(e_v) = b \cdot z(e_v) < \Delta(\theta_H)$$

we find that the benefits created with the VA are enough to induce the participation of the firm type L but not firm type H.

In this scenery firms type H will face a graphic similar to the one presented in figure 10, and, as a consequence, all of the firms will free ride, while the firms type L will face a "fully privilege game" (figure 9) and so will choose to participate.

We might say that the VA will be participated by the firms type L creating a grand cooperation between firms type L.

Maintaining the same reasoning it would be possible to replicate all the equilibrium solutions that were defined for the two person game, but now instead of having the participation of no payers (PDG), one player (PG) or both players (FPG), we would fine solutions involving none of the N players (PDnG), both groups of players (grand cooperation → FPnG)) or only one group of players (PnG)

Heterogeneity (spillover as an imperfect public good)

The decision to participate must now consider the gains that result from the capacity to access the exclusive benefits of the imperfect public.

With $0 < \beta < 1$, the normal form of the n game with the two marginal firms will be:

		(marginal) Firm type k	
		Participating	Not Participating
ι	Participating	$c(e_v,\theta_L) - [b_L \cdot (K_L+1) + b_K \cdot (K_K+1)] \cdot z(e_v)$ $c(e_v,\theta_K) - [b_L \cdot (K_L+1) + b_K \cdot (K_K+1)] \cdot z(e_v)$	$c(e_v,\theta_L) - [b_L \cdot (K_L+1) + b_K \cdot K_K] \cdot z(e_v)$ $c(e_v,\theta_K) - \beta \cdot [b_L \cdot (K_L+1) + b_K \cdot K_K] \cdot z(e_v)$
	Not Participating	$C(e_v,\theta_L) - \beta \cdot [b_L \cdot K_L + b_K \cdot (K_K+1)] \cdot z(e_v)$ $c(e_v,\theta_K) - [b_L \cdot K_L + b_K \cdot (K_K+1)] \cdot z(e_v)$	$c(e_v,\theta_L) - \beta \cdot (b_L \cdot K_L + b_K \cdot K_K) \cdot z(e_v)$ $c(e_v,\theta_K) - \beta \cdot (b_L \cdot K_L + b_K \cdot K_K) \cdot z(e_v)$

And the new condition to have Participation as a dominant strategy, for a firm belonging to a group type ι, is now;

$$C_P(K_\varphi) < C_{NP}(K_\varphi)$$

With,

$$\Delta(\theta_\iota) \leq b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$$

as a sufficient condition.

Due to the difference in the slopes of $C_{P(K\varphi)}$ and $C_{NP(K\varphi)}$ curves, it is now possible to encounter three different equilibrium situations for each group:

(A) $C_{P(K\varphi)} > C_{NP(K\varphi)}\ \forall\ N_\iota \Rightarrow$ PDnG $\Rightarrow$ no firm type ι wants to Participate (figure 11)

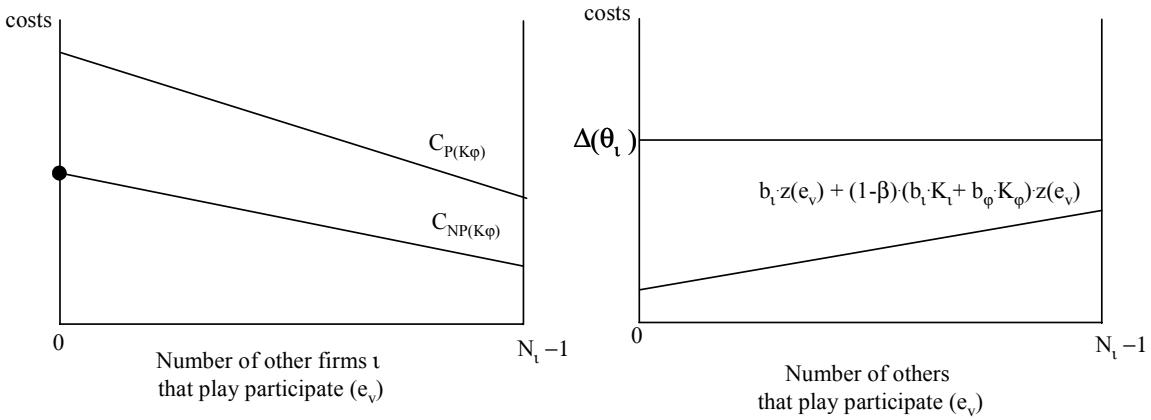


Figure 11

In the right side of figure 11 we find two curves:

- $\Delta(\theta_\iota)$ → a horizontal line representing the excess cost firm ι pays for participating; this value is independent of the number of K_ι participating firms
- $b_\iota \cdot z(e_v) + (1-\beta)\cdot(b_\iota \cdot K_\iota + b_\varphi \cdot K_\varphi)\cdot z(e_v)$ → "extra benefit function" representing the extra benefit that firm ι attains when it decides to participate; this function is now dependent on K_ι because ι is no longer a " pure public good".

The equilibrium in the ι group implies that no one participates when the "extra cost" curve is higher that the "extra benefit function" for all values of K_ι.

(B) $C_{P(K\varphi)} < C_{NP(K\varphi)}\ \forall\ N_\iota \Rightarrow$ PnG $\Rightarrow$ all the firm type ι want to Participate (Figure 12.)

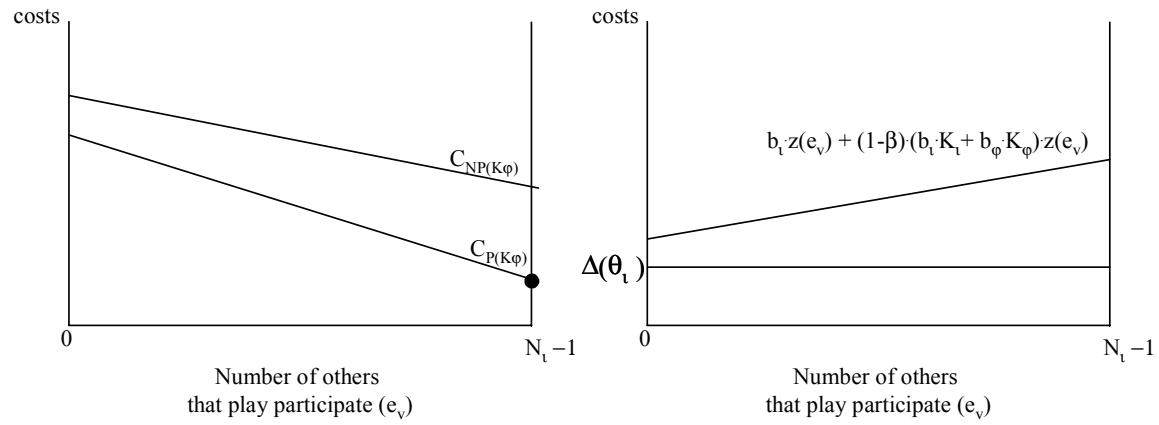


Figure 12

(C) $C_{P(K\varphi)}$ and $C_{NP(K\varphi)}$ cross at a point $K_\iota \Rightarrow$ TnG → Tipping n Game

Because of the differences in slopes between $C_{P(K\varphi)}$ and $C_{NP(K\varphi)}$ we find a new game structure (figure 13).

In this situation we encounter tow equilibriums for the group type ι, in pure strategies: either all of the firms from the group play participate ore none will play participate.

To K_ι^* we will call the "tipping" number of participants, in the sense that it is the minimum number after which all firms type ι prefer to participate (inspired on the Barrett, 2003, "tipping game").

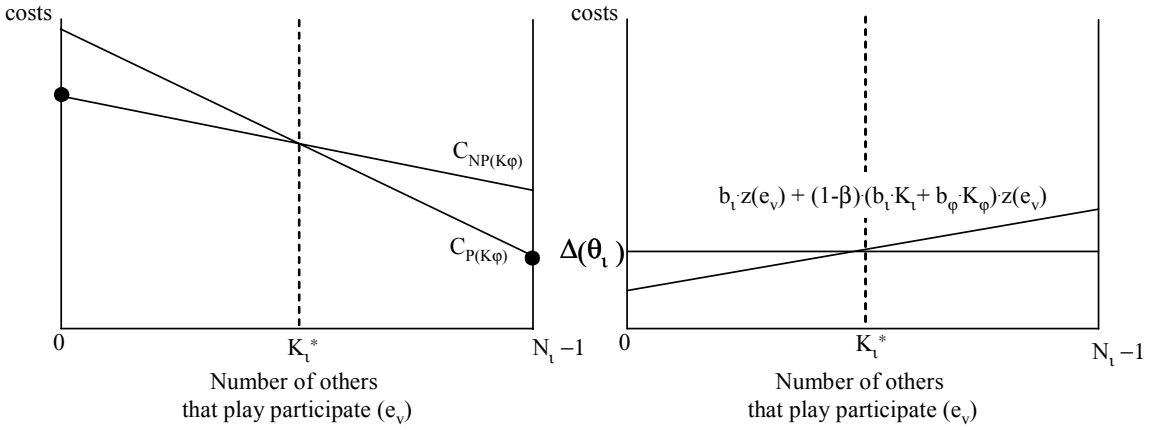
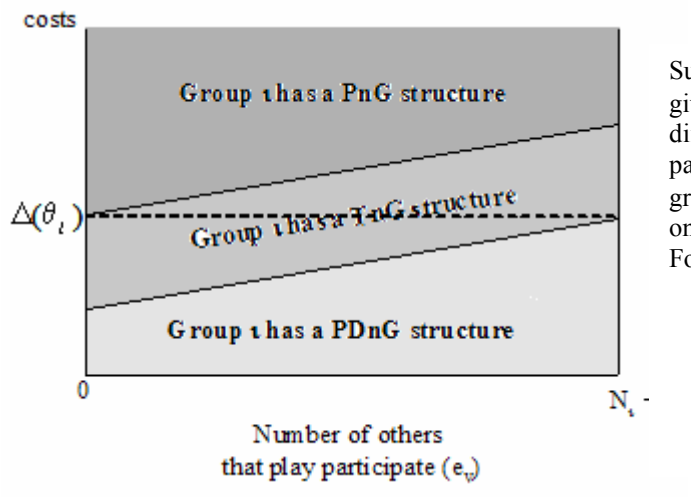


Figure 13



Summarising the information:
given a value to $\Delta(\theta_\iota)$, and considering different "extra benefit functions" parallel to the two sloped lines in the graphic, we can say that group ι faces one of three structures:
For extra benefit functions in:

- Lighter grey area a PDnG structure
- Middle grey area a TnG structure
- Darker grey area a PnG structure

From what was already said in relation to the influence of having one more firm type φ participating in the game, there are some conclusions that can be taken.

1st Preposition 5 stands when the spillover is not a pure ublic good, and so it is not necessary to analyse situations that start with a PnG structure.

2nd If the group ι is facing a TnG the entrance of a new firm type φ will reduce the K_ι^* tipping number (figure 14), or it can create a PnG structure.

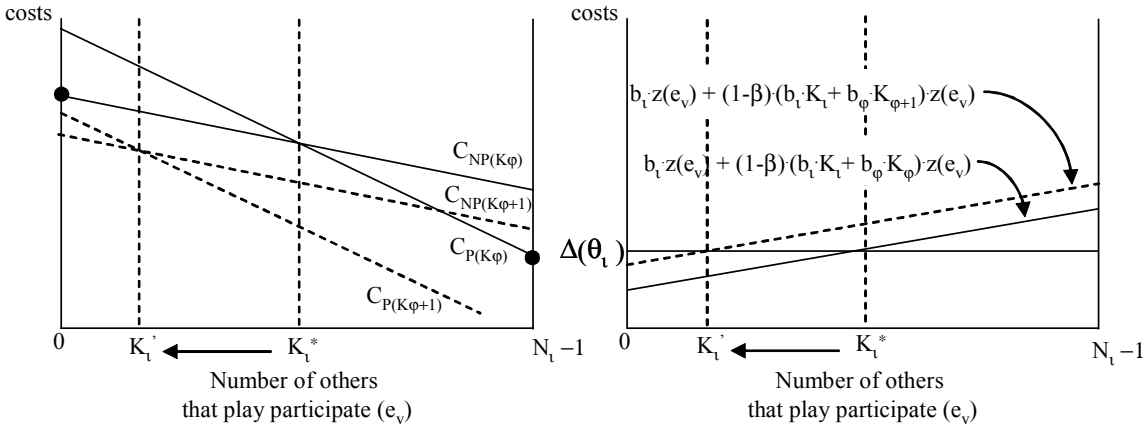


Figure 14

3rd There is no equilibrium in which the groups of firms are divided, i.e., in each equilibrium we will find:

- $K_\iota = N_\iota \rightarrow$ the firms that have a specific type will all decide to participate, in this situation we will refer to Group ι as being a privileged group; or
- $K_\iota = 0 \rightarrow$ non of the firms will participate.

We will now consider the influence of the different relations between b_L and b_H.

$b_H = b_L = b$

In a situation of equality between the benefit that each firms creates in terms of spill over, the condition to participate for a firm ι is:

$$\Delta(\theta_\iota) \leq b \cdot z(e_v) + (1-\beta) \cdot (b \cdot K_\iota + b \cdot K_\varphi) \cdot z(e_v)$$

In the next graphic (figure 13.) we will find:

- the two excess cost functions for the marginal firm H and L, with $\Delta(\theta_L) < \Delta(\theta_H)$,
- five "extra benefits functions" $(b \cdot z(e_v) + (1-\beta) \cdot (b \cdot K_\iota + b \cdot K_\varphi) \cdot z(e_v))$ corresponding to 5 different values for b, considering that non of the firms from the other group will participate, (i.e., $K_\varphi = 0$).

  Due to the equality between $b_H = b_L$ the "extra benefit function", when non of the firms from the other group participate, is the same for both groups:

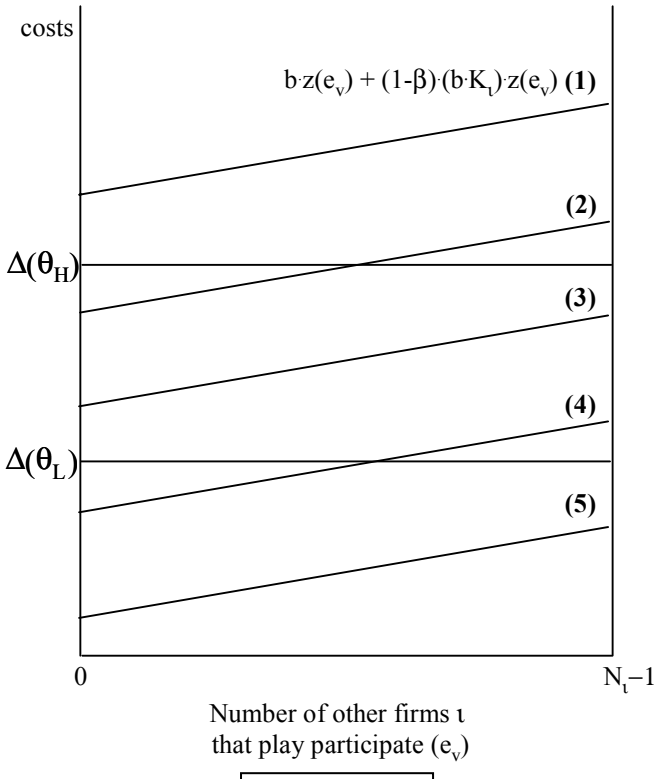


Figure 15

(1) FPnG

Both groups are privilege: regardless of the participation or not of the other group, all the firms belonging to each group will want to participate; the equilibrium will be the "grand cooperation" with the participation of both groups of firms.

(2) PnG or a FPnG

Group L: is privilege,

Group H: is initially (considering $K_L = 0$) in a TnG structure.

With the participation of the L group the "extra benefit function" for group H will move upwards, it then can remain in a TnG structure with a smaller "tipping" number of participants or it can turn into a privilege group.

(3) PnG

Group L: is privilege,

Group H: is initially (considering $K_L = 0$) in a PDnG structure.

With the participation of the L group the "extra benefit function" for group H will move upwards, it then can remain in a PDnG structure, it can become a TnG structure or even it can turn into a privilege group.

(4) PDnG, InGG or PnG

Group L: is in a TnG structure, it can participate depending on the "tipping" number of firms; the "tipping" number can be modified by the participation of group H or can even turn into a privilege group.

Group H: is initially (considering $K_L = 0$) in a PDnG structure.

If L participates can remain in a PDnG structure, it can become a TnG structure or it can even turn into a privilege group.

In this game the participation may require coordination between the firms from the two groups, for which we gave a "pure coordination n game. Has we did in the two game structure we will call this game a "Intermediate n group game" (InGG).

(5) PDnG

Group L: is in a PDnG structure, no firm will want to participate.

Group H: is in a PDnG structure, no firm will want to participate.

$b_\iota \neq b_\varphi$

To introduce differences in the impact each firm has in the creation o the spillover will place the firms of each type in a different "extra benefit function".

On figure 16 (a) and (b) we start with a situation where we find the $\Delta(\theta_\iota)$ and the "extra benefit function" under the initial assumption of $b_\iota \neq b_\varphi$.

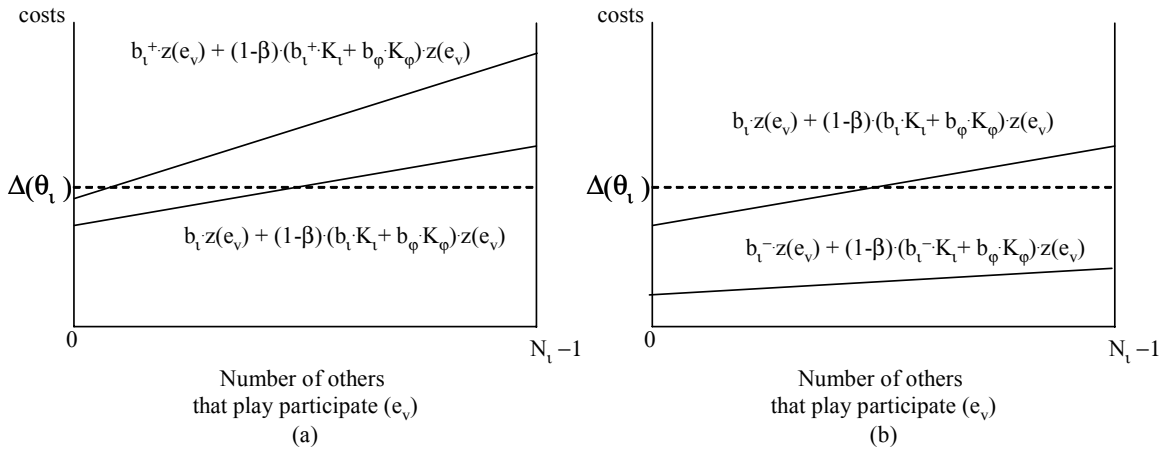


Figure 16

Group ι has a TnG structure with a "tipping" number of firms K_ι.

On figure (a) we maintain b_φ and increase b_ι to b_ι^+. The consequence is the movement upwards of the "extra benefit function" for group ι which also becomes steeper. Group ι maintains a TnG structure with a lower "tipping" number of firms, or becomes a "privilege group".

On figure (b) we face a decrease of b_ι to b_ι^- with a movement downwards of the "extra benefit function" for group ι which become, now, less steeper. Group ι could maintain a TnG structure with a higher "tipping" number of firms start facing a PDnG structure.

In the next two tables we analyse the equilibrium structures for $b_L \neq b_H$.

The first column of the tables gives the relative position of the two "extra benefit function" for L and K, respectively, by reference to the positions on figure 15. We already know that the "extra benefit function" for the group with the higher b will be steeper than the "extra benefit function" for the other group and always located at a higher point.

The next columns point the game structures for each group when the other group doesn't participate (on the left) and when the other group chooses to participate (on the right).

Last column indicates the characteristics of the full equilibrium situation.

$b_L > b_H$					
Position (L,H)	L Structure for $K_H = 0$	L Structure for $K_H = N_H$	H Structure for $K_L = 0$	H Structure for $K_L = N_L$	Equilibrium (Groups participating)
(1,1)	Privilege	Privilege	Privilege	Privilege	FPnG (L,H)
(1,1) (2,2)	Privilege	Privilege	TnG	Privilege	(FPnG) PnG (L,H)
				TnG	PnG (L,H)
				TnG	PnG (L)
(1,3) (1,4) (1,5) (2,3) (2,4) (2,5) (3,3) (3,4) (3,5)	Privilege	Privilege	PDnG	Privilege	PnG (L,H)
				TnG	PnG (L,H)
				TnG	PnG (L)
				PDnG	PnG (L)
(4,4) (4,5)	TnG	Privilege	PDnG	Privilege	(PnG) InGG (L,H)
		TnG		TnG	(PnG) InGG (L,H)
				PDnG	PnG (L)
					PDnG
(5,5)	PDnG	Privilege	PDnG	Privilege	InGG (L,H)
		TnG		TnG	InGG (L,H)
					PDnG

$b_L < b_H$					
Position (L,H)	L Structure for $K_H = 0$	L Structure for $K_H = N_H$	H Structure for $K_L = 0$	H Structure for $K_L = N_L$	Equilibrium (Groups Participating)
(1,1) (2,1) (3,1)	Privilege	Privilege	Privilege	Privilege	FPnG (L,H)
(4,1)	TnG	Privilege	Privilege	Privilege	(FPnG) PnG (L,H)
		TnG			(FPnG) PnG (L,H)
		TnG			PnG (H)
(5,1)	PDnG	Privilege	Privilege	Privilege	PnG (L,H)
		TnG			PnG (L,H)
		TnG			PnG (H)
		PDnG			PnG (H)
(2,2) (3,2)	Privilege	Privilege	TnG	Privilege	(FPnG) PnG (L,H)
				TnG	(FPnG) PnG (L,H)
				TnG	PnG (H)
(4,2)	TnG	Privilege	TnG	Privilege	(PnG) InGG (L,H)
		TnG		TnG	(PnG) InGG (L,H)
		TnG			PnG (H)
				TnG	PnG (L)
					PDnG
(5,2)	PDnG	Privilege	TnG	Privilege	(PnG) InGG (L,H)
		TnG		TnG	(PnG) InGG (L,H)
		TnG			PnG (H)
					PDnG
(3,3)	Privilege	Privilege	PDnG	Privilege	(FPnG) PnG (L,H)
				TnG	(FPnG) PnG (L,H)
				PDnG	PnG (L)
(4,3) (4,4)	TnG	Privilege	PDnG	Privilege	(PnG) InGG (L,H)
		Privilege		TnG	(PnG) InGG (L,H)
		TnG		TnG	InGG (L,H)
				TnG	PnG (L)
					PDnG
(5,3) (5,4) (5,5)	PDnG	Privilege	PDnG	Privilege	InGG (L,H)
		Privilege		TnG	InGG (L,H)
		TnG		TnG	InGG (L,H)
					PDnG

VII. Final Remarks

The developments presented in this paper are part of an ongoing PHd work on the subject of Collective actions and VAs .

In this sense it is impossible to establish conclusions. The conclusions that we where trying to achieve are presented in the previous sections.

We can however give indications on further developments:

On the theoretical side we will aim to:

- develop further the question of heterogeneity trying to specify de existence of a dominant technology;
- verify the importance of the prepositions presented by Olson;
- confront the results to those achieve in the literature on VAs;
- develop the first and last stages of the game, and look for impacts over the conclusions.

On the empirical analyses, the Portuguese example has been the source for information and it will continue to be. It is however necessary to advance to a more specific analysis on the characteristics of the firms that sign the agreements and in relation to the "club" benefits that are created.

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