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TITOLO TESI

Enhancing resource management in socio-ecological systems: modeling collective conditionality in rural policies

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Acronyms:

Agglomeration Bonus: AB
Agri-Environmental Payment: AEP
Agglomeration Payment: AP
Common Agricultural Policy: CAP
Consorzio di Bonifica della Romagna Occidentale: CBRO
Cooperative Game Theory: CGT
Ecological Focus Areas: EFA
Emilia-Romagna: E-R
European Union: EU
International Environmental Agreements
Minimum participation rule: MPR
Nash Equilibrium: NE
Non-Cooperative Game Theory: NCGT
Rural Development Plan: RDP
Shapley Value: SV
Socio-Ecological System: SES

1 Introduction: cooperation of farmers, rural policies, and collective conditionality constraints

1.1 Background

In recent decades part of the focus of agricultural policies has shifted from the pure support of market prices/production/income toward the management of natural resources. Conservation of biodiversity and ecosystem services, pollution control, and water management (quality and quantity) have become key areas of agricultural policies. In this field, the traditional approach used for promoting environmentally friendly practices has been largely based on support to individual farms (Baylis et al., 2008; Lefebvre et al., 2014). Yet this is less and less considered effective in achieving ecosystem/resource-related objectives. A collective approach has been advocated for policies focusing on the interconnection between agriculture and natural resource management (OECD, 2013). Here, I use the "collective approach" as an umbrella term to refer to any policy scheme that embeds some forms of collective conditionality constraints.[1]

Two main reasons underpin the rationale for a collective approach toward the management of natural resource within the agricultural sector. Often these two types of reasons occur at the same time (Albers et al., 2008). First, biological processes often exhibit threshold effect (Dupraz et al., 2009) and work at the landscape scale (Parkhurst et al., 2002). For instance, an effective biodiversity protection requires the connection of habitats that are often in multiple private properties. In these cases, if the incentive schemes offered by rural policies enable to involve a relatively little number of actors that are scattered around the area, no sensible effect is produced and the policy is ineffective despite the effort. To deal with this issue, the literature have developed the so-called Agglomeration Bonus (AB), a two part incentive scheme where a bonus, in addition to a standard payment, is given only if collective conditionality constraints are met (Parkhurst et al., 2002). For instance, a bonus is granted to clustered parcels that are all enrolled in agri-environmental schemes.

Second, natural resources, in certain circumstances, benefit the agricultural sector itself. Moreover, often such benefits exhibit, to different degrees, non-rivalry and non-excludability characteristics. This is the case for instance of some ecosystem services (Cong et al., 2014), bioinvasion control (Epanchin-Niell and Wilen, 2014) and water management (Madani and Dinar, 2012). In these conditions, the literature highlights how cooperation/coordination of farmers on resource management leads to efficiency gains. However, most of this literature has dealt with cooperation by exogenously determining the size of the coalition, the group of people cooperating, and by simply comparing the full cooperation with a non-cooperative behaviour. However, research on International Environmental Agreements (IEA) has endogenized the formation of coalitions in a public good setting (Carraro and Siniscalco, 1993). Two findings of this vast literature are of interest here. On one hand, partial cooperation is possible, but its gains are very limited. On the other hand, the imposition of a Minimum Participation Rule (MPR) is an effective way to expand the size of the coalition, so that efficiency gains are obtainable (Rutz, 2001). MPRs define a threshold on a minimum

[1] Thus, in this framework, an agglomeration bonus, which gives an additional premium if a number of farms jointly apply biodiversity protection efforts, represent a possible application of a "collective approach". I will use the terms "collective incentives" or "collective conditionality" as synonymous of "collective approach".

number of cooperating agents, above which a coalition is allowed to form. The idea is that a MPR transforms a prisoner dilemma type of game (where the equilibrium is not pareto efficient) in a chicken game (where there are multiple equilibriums, some efficient, and some not) and thus it represents an effective coordination device (Rutz, 2001).

This topic is increasingly relevant for the design of agri-environmental policies. The European Union (EU) envisions and promotes, in certain circumstances, the coordination among farms on the application of environmental efforts, both in the first pillar (for the collective compliance of the "greening" constraints associated with the Common Agricultural Policy -CAP- direct payments) [2] and in the second pillar (suggesting to member states to provide higher payments when groups of farmers are jointly the recipients of agri-environment-climate payments)[3]. Moreover, in the United States, there appears to be increasing interest in the topic, as evidenced by the Oregon Conservation Reserve Enhancement Program (USDA, 1998) or by the cooperation on forestry management (McEvoy et al., 2014). The collective approach is indeed often implemented by applying MPR either on land contracted or on a minimum number of agents involved, above which a payment or a bonus is granted. For instance, in both France and Oregon additional premiums are provided to individual farms when a minimum share of land within a certain delimited area is also enrolled in conservation measures (Dupraz et al., 2009; USDA, 1998). In Emilia-Romagna (E-R), Italy, the Rural Development Plan (RDP), one of the key agricultural policies in the EU member states, provides incentives for the construction of rainwater harvesting reservoirs with the environmental goal of decreasing the pressure on groundwater resources. Eligible projects must meet certain minimum requirements on number of utilizers and reservoir capacity.

Note that a shift from the support to the individual farms to the design of a collective approach for policies requires or de facto assumes a more comprehensive understanding of the complex relationships that occur among policies and farms on one side, and among farms and the environment in which they operate on the other side. The concept of socio-ecological system -SES- (Berkes et al., 2000) and the associated evaluation framework (Ostrom, 2009) and its developments (Anderies and Janssen, 2013) could provide a useful tool for a general understanding of these new policies. Such a framework explicitly assumes the potential range of benefits type that natural resource management delivers (publig good, club good, etc.), the possibility of overcoming free-riding problems, institutional considerations, and thus the complex relations that occur among the key players of SES management (Ostrom, 2007). However, traditionally the SES literature have focused on self-organizing system, and even though public policies are often considered important they are de facto not explicitly modelled (Anderies and Janssen, 2013), at least in the most common form in Europe, namely through incentives.

Even though the topic has been the subject of a greater number of analyses in recent years, many aspects of collective conditionality constraints in rural policies have not been covered by the relevant literature. Here I want to highlight three aspects of such a topic. First, most of the analyses assume that

[2] Art. 46, Regulation (Eu) No 1307/2013 of the European Parliament and of the Council. More precisely, the cited article states that the "greening" constraint regarding the establishment of Ecological Focus Area (EFA) (5% of the arable land) can be collectively implemented. Paragraph 5 notes that the percentage of land devoted to EFA can be set at the regional level in order to have adjacent EFAs. Paragraph 6 allows for contiguous farmers to fulfill the EFA duty collectively.

[3] Paragraph 22 and art 28, Regulation (EU) No 1305/2013 of the European Parliament and of the Council

environmental protection is only a cost from the farmers' viewpoint. Second, as the literature review will show, most of the existing literature has only focused on the profitability of cooperation, but not on its stability. Third, distributional considerations are rarely addressed in the literature (Segerson, 2013). However, they potentially have relevant policy implications that have not yet been covered with respect to agglomeration incentives. Some studies, both theoretical (e.g. Marchiori, 2014) and empirical (e.g. Janssen et al., 2011) highlight how distributional elements are key to influencing the success of collective actions.

1.2 Research objectives

Given these considerations, in this thesis I investigate how collective conditionality constraints associated to incentives aimed at natural resource management affect the private decisions related to the emergence of cooperation among farmers. Two design elements of this type of policies are addressed: ii) the collective conditionality constraint rules (the level of the MPR) and ii) the incentive levels.

In particular, two sub-objectives related to the payment and the associated rules are formulated. I analyse the effect that the design elements have on 1) the stability of collective arrangements among farms, and 2) on the distribution of the benefits among farms. More details follow.

First I assess the effect that incentives and collective conditionality rules (MPR) have on the stability of a group of cooperating people. The term stability refers to a situation when players that cooperate do not have incentives to defect (Botteon and Carraro, 1997), and thus the analysis of the stability of cooperation endogenizes the size of the group of people cooperating, and the associated features of the cooperation, e.g. individual and collective profits, contribution levels, and, in our case, the participation in policy schemes. Such an analysis is applied to three case studies: 1) public goods, 2) club goods, and 3) private costs. With such terms I refer to the type of benefits that effort/action incentivized by the policy have on the rural sector, on the same population of farmers, hence adding to most of the AB literature the possibility that environmental management delivers benefits to the agricultural sector. Thus, in the case of public goods, the subsidized action provides benefits that accrue to the whole population of farmers under considerations, without the possibility to exclude free-riders from enjoying these benefits (apart for the policy subsidy). This might be the case for instance of some ecosystem services, such as rural tourism or pollination service (Cong et al., 2014). In the second case, the club good case, the subsidy incentivizes an action whose benefits can be effectively and costlessly be excluded to those non-providing efforts, and where congestion costs emerge. An example of this could be the construction of irrigation facilities such as collective reservoirs.[4] The third case, the private cost case, deals with AB, assuming that environmental efforts do not yield benefits by themselves, but environmental threshold requires the coordination of a number of farmers to be effective. Note that there are great differences between the cases, especially from the first two and the third one. In both the public good and the club good cases, the policy intervene in a situation where the economic structure of the problem is such that cooperation is profitable, even though other elements

[4] I acknowledge that often irrigation development projects are considered a public good, or a common pool resource, rather than a club good (Ostrom, 1990).

prevent if from *naturally* emerging (stability). In the third case, cooperation is purely linked to the policy design, and thus it is not profitable in the absence of policy payments. The analysis of the stability of the cooperative arrangements in the three cases is theoretical: I assume a homogenous population of farmers, and I use relatively simple mathematical models to assess the relative effect of parameter levels on the key variables at stake. However, the three cases cover a large spectrum of potential conditions that might be faced by policy-makers. For instance, the 2014-2020 E-R RDP provides support for the creation of natural ecosystems (operation 4.4.01, in certain circumstance, public goods), the construction of collective reservoirs (operation 4.1.03, club goods) and buffer strips (operation 4.4.03, private costs). Note also in the 2014-2020 RDP cooperation and coordination among farmers is a key cross-cutting theme, directly indicated by the EU[5], that is promoted for a wide range of rural development aspects, including sustainability of farming, innovation, supply chain management and rural tourism facilities (measure 16 – Co-operation).

Second, I assess the distributional effect that the collective conditionality constraints (MPR) associated to the subsidies have. This case requires a relatively more empirical setting with respect to the previous objective. The assessment of the distributional effect is only applied to the case of club good, with a specific example related to the incentives for the construction of collective reservoirs (measure 125 of the 2007-2013 RDP in E-R.). More specifically, here I analyse how different MPR levels affect the distribution of the benefits related to the construction of the reservoir.

1.3 Methodology rationale

Given the inherent interactive character of the issue at stake, game theory seems to be the most appropriate tool to investigate such an issue. To pursue the thesis objectives, this work departs from the traditional Non-Cooperative Game Theory (NCGT) approach to use a mixed approach (coalition formation) and to use Cooperative Game Theory (CGT) according to the specific problem addressed.

Usually NCGT assumes the impossibility of having binding agreements and lack of communication among players, while CGT usually assumes the opposite. The set of assumptions translates in a different approach toward modelling interaction among players. NCGT explicitly lists all the possible/available strategies and resulting payoffs for each individual player. Since it is possible to have binding agreement, CGT decision-maker is the coalition, a group of players working together, and the main focus is on the stability of possible groupings of players, and on the distribution of payoffs, without modelling the specific strategies that are employed. Coalition formation theory is based on a mixed approach, where at least partial cooperation is possible, even in the presence of free-riding. As it will be clear later in the thesis, "cooperative" does not mean lack of rational behaviour, nor altruism.

Not using NCGT in the context under analysis in this article is justifiable in the light of the considerable amount of anecdotal evidence available regarding communication among players and (de-facto) binding agreements among farmers in a rural community. Note also that a large literature started by the seminal work of Elinor Ostrom has highlighted the possibility that in certain conditions group of farmers actually behave cooperatively (Ostrom, 1990). Given this finding, I translate cooperation among farms by assuming that in the maximization problem each individual in certain conditions will

[5] Article 35, Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013.

maximize taking into account the benefits not only of him/her self but the benefits of a group of people. Note that this however does not fully resolve the problem, since issue of stability could limit the extent of cooperation.

In particular, in the analysis of the stability I use two concepts widely used in the literature: the internal/external stability and the core (Table 1.1).

The concept of the core is one of the key solutions developed by the CGT literature. In contrast to NCGT, CGT assumes the possibility of having binding agreements and of communication among players, in an economic setting where cooperation represents the pareto optimum. Coalitions are the players of a CGT setting, and the usual goal of such an analysis is the distribution of the benefits of cooperation. The notion of the core defines when such a situation can yield a stable outcome: the core is "a set of socially stable distributions, (…) which cannot be overthrown by any coalition acting in its own interests" (Shapley and Shubik, 1969, p. 678). Indeed, in case the core is "empty", cooperation is likely not to emerge, even though led to the highest profits, since players cannot find a way to distribute profits. The concept of the core has been often applied to club-good type of economy both in theoretical setting (Pauly, 1967) and in application to agricultural economics issues such as the formation of cooperatives (Mérel et al., 2015; Sexton, 1986). In line with this, I use the concept of the core to define the stability of the second case study and on the third case study, where there are no spillovers across the coalitions, or, the value of the coalition purely depends on actions of the members.[6]

The "internal/external stability" is a notion of stability developed within the cartel formation literature (d' Aspremont et al., 1983), but subsequently used in the literature on IEAs (Barrett, 1994; Botteon and Carraro, 1997) to assess e.g. the number of countries ratifying agreements on climate change emissions. Indeed such a concept has been often applied to a public good situation, to assess how many players will decide to cooperate in case their actions will benefit even free-riders. The idea of such a stability notion is that a group of people cooperating is stable in case no-one has incentives to leave the coalition, and no one has incentives to join it. The coalition cooperates and behaves non-cooperatively with the rest of the players. I will use such a concept for the first case study, the public good example, in line with the IEA literature.

For the second sub-objective, the analysis of the distribution of the benefits, I use one of the most important solutions developed by CGT: the Shapley Value (SV). The SV gives a normative and unique solution to the problem of allocating the worth of a group of agents working together so that no one has incentives to withdraw from the group by defining a share that is rationally acceptable by all players (in contrast to the core, which defines a set of solutions, not a unique one). The SV can be interpreted as an estimate of the expected value of cooperating when social preferences on institutional arrangements are unknown (Slikker and van den Nouweland, 2012). However, given that the SV can only be applied to cases in which the profitability of cooperation has already been verified, I overlook

[6] Note however, that the core has been also used for spillovers type of setting, but additional assumptions on the behaviour of agents is required (Breton et al., 2006; Chander and Tulkens, 1995)

at the problem of mechanism design, which would be a prior step. In keeping with this, I take as exogenously given the policy rules that I investigate here.

	Methodology	
Case studies: Type of benefits (on the farmers' population)	**Stability and subsidy (stability concept)**	**Distributional effects (solution)**
Public good	internal/external stability	
Club good	Core	Shapley Value
Private costs	Core	

Table 1.1. Case studies, thesis objectives and methodology applied (stability and solution concepts).

1.4 Thesis overview and positioning with respect to the existing literature

In general the thesis tries to merge the lessons of the SES literature with the analysis of policy aimed at natural resource management in rural areas. With respect to the former, the thesis is an attempt to gain further understanding, beyond the mere rule of the game, for the design of policies aimed at fostering cooperation and coordination within SES in order to improve natural resource management. As it was noted earlier, the SES literature have only vaguely addressed the policy implications of its findings, which are however crucial for example in Europe where policies deeply affect the rural sector. With respect to the latter, the thesis tries to address a more comprehensive account of both the benefits of environmental efforts on the rural sector and of the farmers' behaviour and the possibility of their coordination.

In the next section, 2, I briefly review the relevant literature on the topic. After having indicated the main policies that have suggested a collective approach toward natural resource management in agriculture, the review focuses on three topics: 1) the AB, 2) the MPR as a coordination device, and on 3) the relevance of distributional considerations for collective actions.

In section 3 I focus on the first thesis objective, namely the problem of the formation of the coalition and its stability. First a brief introduction describes the two concepts of stability that I will subsequently use. In section 3.2 I assess how the stability of a coalition, and thus its formation, is affected by rural policies, in a setting where actions of farmers exhibit public good type of benefits. There is an increasing but limited number of papers that address the benefits on the farmers of the environmental actions they provide (Albers et al., 2008), which includes control of invasive species (Epanchin-Niell and Wilen, 2014), pollination services (Cong et al., 2014), or rural tourism (Zavalloni et al., 2015). In these examples coordination/cooperation among farmers would yield substantial gains with respect to individual profit maximization. In contrast to this literature that either assumes full cooperation or non-cooperative behaviour, I analyse whether and to what extent partial cooperation can emerge and which policy elements can be used to foster it, by developing a standard model of coalition formation used in the IEA literature. Moreover, all these papers have a spatially explicit framework, which surely addresses an important aspect of the issue, but lacks of generalizability of the results. Instead, I use a relatively simple model that I solve analytically to assess general conditions.

In section 3.3 I analyse the case of club goods, relying for the stability issue on the concept of the core. While taking a general form, the analysis is inspired by an existing policy in E-R, measure 125 of the 2007-2013 RDP, which subsidizes the construction of collective reservoirs (a club good) to reduce the pressure on groundwater resource. Here I apply findings of previous studies to assess in which conditions a subsidy on a club formation, and collective conditionality constraints, can be used by policy makers. Usually the literature on SES, that has widely used irrigation infrastructure as the ideal-typical object of analysis, has 1) used non-cooperative setting, and 2) de-fact overlooked at the role of public policies. In contrast with this, I take a CGT approach to assess whether incentives and MPR can be used to ensure or to foster the development of irrigation infrastructure exhibiting club good type of benefits

In the last subsection I focus on the AB scheme. In particular a standard AB model has been reformulated in terms of CGT. Here the incentives to cooperate are purely set by the policy, so the core is directly applied to the policy schemes in order to observe how to design such a payment in such a way that the core is non empty. Even in this case, the literature has mostly used non-cooperative settings and laboratory experiments. The use of CGT in such a case would add an additional dimension to the analysis of the design of AB.

In section 4 I address the distributional effect of policy incentives. Such a case further deepens the analysis of section 3.3 on club and policy, in relation to water resource development projects, to compute the SV of a collective reservoir. The analysis simplifies the problem (number of players and associated MPRs) to maintain the tractability and intelligibility of the game. The model is however parameterized as much as possible on data taken from an area where irrigation water is managed by the Consorzio di Bonifica della Romagna Occidentale (CBRO). The simplification on the number of players enables a comprehensive assessment of the structure of the decision-making problem faced by the players (optimization of gross margins) and the effect of the MPR on the distribution of their benefits. After such a more theoretical analysis, I formulate an empirical assessment of the SV of investing in a common reservoir. The analysis deals with the accounting of the spatial dimension and of the social environment in determining the bargaining power of players. The reference literature, as for section 3.3, is the SES one. The analysis shows how policy can have an effect on the distribution of the benefits of a collective reservoir by mean of changes in the bargaining power due to different MPR.

Finally section 5 and 6 present respectively the discussions and the conclusions, including some general policy recommendations and directions for future research.

2 Review: policies, agglomeration bonus, Minimum Participation Rules and distributional considerations

2.1 Policy

2.1.1 European Union

Traditionally the CAP approach to the management of natural resources is to target the single farms (Lefebvre et al., 2014). Some forms of collective implementation existed anyway. In UK the Agri-environmental scheme provides some contributions to incentivize the coordination of farms to preserve natural resources. One of these schemes (UX1 option) applies for two or more farms and involves the creation of a Local Commoners Association with a specific sets of binding agreements and internal institutional rules (Franks and Emery, 2013). Concerning water quality, in France AEP designed for the application of buffer strips are increased by 20% if at least 60% or the river bank is not cultivated (Dupraz et al., 2009).

At the EU level the 2014 CAP reform marks a change, since both in the first pillar and in the second pillar, a collective implementation of the duties linked to the single farm payments and of the agri-environment-climate payments are suggested.

In the first pillar, the EU introduces some forms of collective approach for the implementation of the Ecological Focus Areas (EFA), one of the requirements of the greening constraints associated to the CAP direct payment (art. 46, Regulation (Eu) No. 1307/2013 of the European Parliament and of the Council). Such a regulation applies to farms larger than 15 hectares, which are compelled to dedicate from 5% to 7% to EFA. The collective approach is suggested by paragraph 5 and paragraph 6 of the same article. Paragraph 5 indicates that up to half of the percentage points can be met at the regional level in order to cluster the potentially scattered EFAs. Paragraph 6 allows for the creation of contiguous EFAs by group of farmers. Such a collective compliance can be implemented by a maximum of ten farms, and each farmer must locate at least half of his/her EFA duties on his or her holding. Note that from the point of view of the farmers, the two paragraphs do not explicitly indicate any clear incentives or advantage for them to embrace such a collective approach.

In the second pillar, the EU highlights the synergies that might emerge if groups of farmers are jointly the recipients of agri-environment-climate payments, and gives the possibility that the local RDP includes these types of policies (Regulation (EU) No 1305/2013 of the European Parliament and of the Council). This is clearly indicated by article 28 paragraph 2: "Agri-environment-climate payments shall be granted to farmers, groups of farmers or groups of farmers and other land-managers". Transactions costs are cited in paragraph 6, where the regulator suggests that the payments should be increased by 30% in case of collective implementation to cover the potentially higher transaction costs.

2.1.2 Emilia-Romagna

In Italy the E-R region has increasingly enhanced the support for collaborative agreements among farms within the measures of the RDP[7].

With respect to biodiversity conservation goals, both the 2002-2007, and the 2007-2013 RDPs set "environmental agreements"[8], which envision the development of a plan entailing the coordination of a number of farms and other agents across the landscape. In the 2000-2006 RDP the agri-environmental agreements had the objective to promote the coherence among the application of different measures in the most critical regional areas. As such, the agreement represented a model of territorial management. The agreements deal only with two measures: "2f - agri-environmental measures for the diffusion of low environmental impact production systems and conservation of natural areas, conservation of biodiversity ad preservation a restoration of landscape", and measure "2h - afforestation of agricultural land". The implementation of agreements envisioned a mixed approach: they had to be promoted by collective entities but had to be developed with, and signed by, farmers. The applications for the AEP of farmers participating in such agreements had the priorities in the ranking for the financial support.

In the 2007-2013 RDP, agri-environmental contracts are maintained with respect to measure 214, 216 and 221. Again the focus is on a model of territorial management, rather than a focus on the individual farms environmental efforts, since the RDP indicates that the minimum size of land enrolled in such agreements cannot be lower than the 40% of the critical areas indicated by the regulator. Note however that that the concepts of territorial management and critical areas are extremely vague in the policy documents. Farmers enrolling land under these agreements have a higher support

Following the indication of the European Commission, the 2014-2020 RDP further fosters the coordination and cooperation of farmers in many of the issues tackled by the RDP (like rural tourism, or supply chain). To focus only on the topic of the thesis, collective approach is envisioned for the application of buffer strip, supported by measure 10, operation 10.1.08 "management of buffer strip to contrast nitrates". In such a measure, the association among farms is incentivized by increasing the payment up to 30% of the normal agri-environment-climate payment. Measure "16 Cooperation" is fully dedicated to, indeed, cooperation. Sub-measure 16.5 deals with the coordination and cooperation of agents with respect to agri-environment-climate action, through two operations: "operation 16.5.01 preservation of regional biodiversity" and "operation 16.5.02 collective approach toward GHG and ammonia emission reduction". While the implementation guidelines are not yet published, the current version of the RDP documents indicate that minimum constraints for these type of projects could be introduced

Concerning water quantity, the E-R RDPs provide incentives for the construction of rainwater harvesting reservoirs with the environmental goal of decreasing the pressure on groundwater resources. This measure defines two sets of eligibility constrains for the potential projects: one on the minimum size of the reservoirs (greater than 50000 m^3), one on the minimum number of farmers participating (20).[9] Although provisional, the RDP 2014-2020 (E-R, 2014) still provides financial support for

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[7] The Italian government delegates the formulation of the RDP to the regional administrations.

[8] "Accordi agro-ambientali".

[9] In the 2000-2006 RDP such a measure is described in the Axes 3, measure 3q; in the 2007-2013 RDP such a financial scheme is granted by Axes 1, measure 125.

collective projects related to the enhancement of irrigation infrastructure ("operation 4.1.03, collective reservoirs and distribution networks").

2.2 *Review on Agglomeration Bonus*

In this section I review the literature on the AB. The main methodologies used are laboratory experiments and mathematical programming models. The first 3 papers I review are lab experiments dealing with the elements that facilitate the coordination of players (Banerjee et al., 2014, 2012; Parkhurst et al., 2002). The remaining papers are based on mathematical models that instead focus on the effectiveness of different type of incentives (Albers et al., 2008; Drechsler et al., 2010; Wätzold and Drechsler, 2014).

A paper by Parkhurst et al. (2002) was one of the earliest analysis of AB. The authors design an experiment that simulates a spatially explicit land allocation problem with heterogeneous land quality, where payments are offered to retire parcels of land. An AB is introduced and it adds interdependence between the players. The AB is composed by two elements: a fixed part, and a bonus that increases with the amount of contiguous parcels. Players are subjects to three treatments: 1) no AB, 2) AB with no communication, and, 3) AB with pre-play communication. Two types of pairings are explored: matched and random, both under the previous treatments. Random pairing is interpreted to simulate a long-term contract. Results show that communication and long-term contracts greatly increase the probability that players find the dominant Nash Equilibrium (NE), i.e. the contiguous habitat selection.

Banerjee et al. (2012) further analyse the topic by assessing the effect of number of players on the coordination result. They design an experiment where players are connected to each other in a local network, and they test the different patterns of choices of NE on different network sizes (6 and 12 players). They formulate an AB that is increasing in the number of contiguous habitat (neighbours), but that targets two different land use type (k and m), so that the benefit structures exhibits trade-offs between profitability of the schemes and riskiness (selecting habitat m gives the best outcome but only when all the neighbours choose it as well, otherwise the benefits are lower than choosing habitat k). Results show that network size highly affects coordination patterns, and that the most profitable (and risky) AB is more likely to be chosen in the small network.

Banerjee et al. (2014) focus on the availability of the information on the choices of the neighbours. Players are again located in local networks. Results indicate that greater information on neighbours choices help choosing the efficient outcome, but it seems that experience in playing does not help. The efficient outcome generated by AB seems to be a short-term goal that cannot be sustained in the long-run.

Albers et al. (2008) develop a spatially explicit model used to analyse conservation efforts of private agents in a setting where conservation exhibits public good type of benefits. Moreover, they consider both the effect of AB type of incentives and at the same time the implementation of public conservation strategies (like national parks). Key focus of the paper is the investigation of the effect of different type of environmental production function on the private conservation choices. Results show that public conservation actions positively (negatively) influences private actions when the benefit derived by the conservation exhibits increasing (decreasing) marginal returns. Thus, the characteristic of the benefits produced by landscape protection should be taken into account in the design of environmental policies.

Drechsler et al. (2010), rather than focusing on the coordination problem, focus on the effectiveness of an Agglomeration Payment (AP) with respect to a normal homogenous payment. An AP is a scheme where the payment is obtained only if a certain spatial configuration is met (in contrast to the AB, where a bonus is added to a standard payment). The interaction among three effects determine the relatively effectiveness of the two types of payments: 1) the connectivity effect: contiguous habitat increase the biodiversity level; 2) the patch restriction effect: the fact that under an homogenous payment only the cheapest land is allocated to conservation, and 3) the surplus transfer effect: by allowing side payments an AP would enable the enrolment of lands that would not otherwise be enrolled. The analysis applies a spatially explicit model to the conservation of butterfly in a German region. The results show that the surplus effect dominate all the other effects and make the AP more cost effective than homogenous payments.

Wätzold and Drechsler (2014) further deepen the issue, by comparing homogeneous payments, AB and AP in terms of cost effectiveness ("maximisation of conservation output for given opportunity costs of the conservation measures", pag. 87) and budget efficiency ("maximisation of output for a given conservation budget required for the payments to the landowners" pag 87). The results highlight how the AP is better than the homogenous payment both in term of budget efficiency and in term of cost effectiveness. Moreover, results suggest that AP is the most appropriate scheme for low budget, whereas for high budget its relative advantage is reduced.

2.3 Review on cooperation in agriculture and Minimum Participation Rules

Here I first review two papers, in addition to Albers et al. (2008), that have showed how cooperation and coordination of farmers on natural resource management can achieve high social gains (Cong et al., 2014; Epanchin-Niell and Wilen, 2014). Since this literature has however not endogenized the size of the coalition, next I review the literature on IEA, which uses models of coalition formation that indeed take the coalition size as an endogenous variable.

Epanchin-Niell and Wilen (2014) spatially explicitly analyse the problem of bioinvasion control in an agricultural landscape. Bioinvasion takes the form of a public good, since lack of action to eradicate the invasion could reduce the efficacy of actions taken elsewhere. In this context the authors assess the potential of three decision-making frameworks: unilateral management, local cooperative management and neighbourhood cooperative management (the difference between the last two is marked by the number of farmers cooperating). The size of the coalition is exogenously determined. The results show that cooperation can entail large gains with respect to no control and individual controls. Coherently, some forms of incentives conditional on the cooperation of agents is suggested as a policy. Similar analysis and conclusions are drawn by Cong et al. on the conservation of patches yielding pollination benefits (2014). The authors compare the outcome of uncoordinated, non-cooperative, management decisions with the results reached by a cooperative, landscape scale management of natural patches. In this case the cooperation size is the entire population of farmers, and exogenously given. Results also show that cooperation would yields substantial benefits, but that a prisoner's dilemma type of benefit structure could impede such an efficient solution.

How to endogenize the size of the coalition? How many farmers will cooperate? And how to design policies that foster cooperation of farmers? The IEA literature has addressed the issue of the endogenous formation of coalition in a public good setting. Carraro and Siniscalco (1993) and Barrett (1994) focus on the possibility of environmental cooperation among self-interest national states. International environmental protection is a pure public good, with the classic incentives to free-ride. The main idea of this literature is to analyse in these conditions when (partial) cooperation (signing the IEA) is a stable equilibrium of the game. The general setting is usually a two-stage game solved by backward induction. In the first stage countries decide whether to sign or not an IEA having in mind that in the second stage the amount of environmental protection applied is determined, in a Cournot or Stackelberg environment. Usually the models assume that there are players that cooperate, the coalition, whose objective function is the maximization of the aggregate benefit of the coalition itself, and whose size is endogenously determined. Players outside the coalition maximize their own payoffs, taking for given the behaviour of all the other players, including the coalition. The IEA, the coalition, is a self-enforcing equilibrium if 1) no players outside the coalition find profitable to join it, and 2) no players inside the coalition would find free-riding more profitable. Such a stability concept is drawn from the literature on cartel formation (d'Aspremont et al., 1983). The models then usually focus on the size of the stable coalition, and on how to improve it.

The basic setting yields rather pessimistic results, with the stable coalition being relatively small (Barrett, 1994). Moreover, considering a continuum of players rather than integer number of players give even more pessimistic results, since the stable coalition would yield the same level of environmental protection that is delivered by the free-riders (Rutz and Borek, 2000).

However, many IEA have a clause that the enforcement of the agreement occurs only after a predetermined number of countries sign the agreement. The observation of this fact stimulated the analysis of the effect of MPR on the stability of the coalition. The first paper on the topic is by Black et al. (1993), who analyse the topic in an incomplete information model, but the stability of the coalition is not addressed.

Rutz (2001) instead analyses whether an exogenous MPR leads to a stable equilibrium, and in which conditions. Consider a public good game where the public good benefit function is increasing and concave, and the cost function is increasing and convex. Further assumptions are those previously described: two stages, backward inductions, and Cournot type of competition among players and the coalition. Figure 2.1, left, taken from Rutz (2001), shows the payoffs of the coalition ($\Pi_s(k)$) and the payoffs of the singletons ($\Pi_n(k)$) for different levels of coalition size; the equilibrium of the game, considering a continuum of players, is indicated by K_0 (the coalition is stable when $\Pi_n(k)= \Pi_s(k)$). With the MPR in place, (Figure 2.1, right) no coalition is allowed to form if the size of the coalition is lower than a given threshold ($\bar{k}$, in the figure), so below the MPR all the players act non-cooperatively and get the payoffs of full free-riding (bold curves). k^* is the stable coalition when players are integer numbers, and thus the coalition is internally stable if $\Pi_s(k)\geq\Pi_n(k-1)$ and externally stable if

$\Pi_n(k) \geq \Pi_s(k+1)$. The figure shows that if the MPR is binding, namely if it is higher than K_0, the coalition of size $\bar{k}$ (the MPR) is actually stable. Indeed, a coalition smaller than $\bar{k}$ gets the payoffs of full free-riding, which is surely lower than the payoff of the coalition of size $\bar{k}$: so the internal stability condition is met. Moreover, observe that increasing the size of the coalition yields a payoff that is lower than the payoff of the free-riders: so even the external stability condition is met. Observe that the MPR leads to a better outcome for both free-riders and members of the coalition than without the MPR, and thus the MPR leads to efficiency gains.

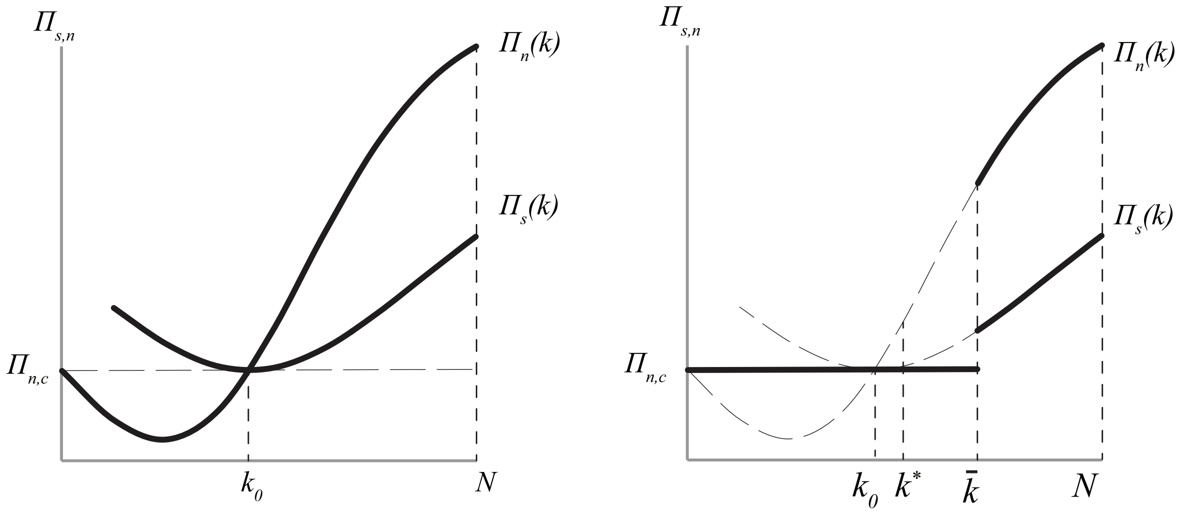

Figure 2.1. Left: value of coalition members $\Pi_s(k)$ and free-riders $\Pi_n(k)$ without MPR. Right: value of coalition members $\Pi_s(k)$ and free-riders $\Pi_n(k)$ with MPR. Note that the value of both for coalition sizes lower than the MPR are set to the standard, fully non cooperative game. Redrawn from Rutz (2001).

Carraro et al. (2009) endogenize the level of MPR by adding a third stage to the classic game. Thus in the first stage players unanimously choose the level of the MPR, knowing that in the second stages they will have to choose whether or not to participate in a IEA, and in the third stage they will choose the level of environmental protection that they will apply. Thus in addition to the stability conditions previously described, the MPR level that will be selected must also satisfy the conditions that the profits of both signatories and non-signatories are higher than without the MPR. Weikard et al. (2015) extend the analysis to the heterogeneous countries settings.

Brau and Carraro (2011) apply a model of coalition formation to an example that is closer to the issue here at stake. The authors analyse the formation of Voluntary Agreement (VA) among firms in an oligopolistic market where the benefit from cooperation are due to cost savings. They include in the model a regulator, whose objective function is the maximization of the social welfare, and the possibility that he or she can affect the design of the VA by threatening stricter environmental regulation in case pollution is not reduced. The options regarding the design of the VAs are two: a free VA, and a VA subject to the imposition of a MPR on the emission level, with to the possibility of stricter regulations in case the MPR is not met. The model results suggest two main policy implications: the regulator should attempt to reduce the benefits for the free-riders, and that should impose a MPR on the VA.

Beyond theoretical models, a few other papers analyse the issue of voluntary agreement and MPR by using experimental and survey analysis. McEvoy et al. (2014) analyse in a laboratory experiments different aspects of the Cooperative forest management Agreements (CA) in the USA. Such agreements are an attempt to cooperatively manage small private forest by pooling information, resources and equipment. These agreements are considered an effective way to prevent the conversion of forest toward other land uses by increasing the return from forestry activity. The aim of the paper is to experimentally analyse how different institutional rules affect the effectiveness of this type of agreements. Participants in the experiments face three choices related to the available land: sell the land, postponing the choice, or enrol the land in a CA. The benefits from participation in the CA are modelled as a club good with spillovers. Three are the rules analysed: 1) a "money back guaranteed", when a given threshold on total enrolled land is not met, the land is given back to the owner; 2) a threshold on the individual participation in the CA, threshold below which the entrance in the CA is not granted; and 3) different CA contract length. Results show that setting the minimum individual contribution is not helping the establishment of the CA. The most promising institutional rule is the setting of the money back guaranteed coupled with long contract.

McEvoy et al. (2015) empirically test the efficacy of the coordination device of MPR in a laboratory experiment. They design an experiment were players face a coalition formation problem for the provision of a public good. In the first stage they vote for the MPR level, and in he second stage they decide whether or not participate in the coalition. The theoretical model behind the experiment entails that rational players should vote for the MPR level that leads to the efficient coalition size. Two treatments are considered: in one case the efficient coalition is the entire population of players, in the second treatment the efficient coalition is smaller that. The result highlights how the players vote for the efficient MPR (60% of the votes), but interestingly in the second treatment only 61% of the time the coalition is formed, vs 91.3% of the time in the first treatment. Such a result cannot be explained by rational behaviour, but can be addressed by model that account for inequality aversion, indicating how benefit distribution could play a role for the emergence of cooperation among players.

Kesternich (2015) using online surveys investigates the preferences of delegates to the United Nations Framework Convention on the level of MPR regarding both the minimum number of participating countries, and minimum amount of emission reduction. Results indicate that preferences are rather different according to country of origin. Small countries prefer rather high MPRs that thus can ensure them a greater bargaining power. On the other hand, bigger economies favour more the formation of smaller coalition (relatively low MPR) and relatively high emission reduction quantities.

2.4 Distribution

As noted by for instance Segerson (Segerson, 2013), in certain circumstances the distribution of benefits generated by policy is as much as important as efficiency. There is an enormous literature on the topic of the relationship between inequality and efficiency, like for instance in the public good contribution. Here I do not attempt to extensively review this literature, but only to present some papers that shows the importance of equity distribution in case of collective interactions among players, results that are most likely to be considered important in case of policy that assumes a collective approach. In the following I analyse first a theoretical model that links heterogeneity of players to the sharing rules that optimize the aggregate profits linked to a collective water resource development project. Next I analyse three experimental analyses that focus on the relationship between the individual contributions to a public good game and the distribution of benefits.

Marchiori (2014) formulates a simple two players model aimed at assessing the sharing rules that determine the optimal aggregate profits. Two farmers can invest in a public infrastructure, which delivers water. The infrastructure production function is parameterized with different degree of complementarity in the individual efforts. The two farmers are characterized by different land endowments that determine their heterogeneity. The author identifies two forces, working in the opposite direction, that determine the optimal sharing rule. The first one is the "effort-augmenting" force that pushes water toward the player with the higher water marginal productivity; the second one is the "effort-mix" force that pushes toward an equalization of the water distribution to ensure that the required mix of effort is provided. This clearly depends on the degree of complementarity/substitutability of the efforts: when efforts are relatively more complementary (substitutable), the effort-mix force (effort-augmenting) is predominant over the effort-augmenting (effort-mix force).

Kube et al. (2015) focus on the emergence of institutions that solve free-riding problems in a public good game. More specifically they analyse by using a lab experiment how the heterogeneity of players, and the asymmetry in the institutional constraints, affect the emergence of institutional coordination. The experiment runs as follow. Players have an endowment of resource that has to be allocated between private consumption and public good provision. Before playing the public good game, they can also vote on an institutional setting that, once unanimously accepted, fixes the individual contribution to the public good. By differentiating 1) the marginal return to the public good among the players, and 2) the institutional obligations, the authors estimate the effect of inequality aversion on the institutional emergence and the trade-offs between inequality aversion and efficiency. In the "homogenous players" case, players have the same private returns from public good; in the heterogeneous case, players have either high (subscript *h*) or low (subscript *l*) return from public good. Two types of institutions are analysed. The symmetric institution is set so that efficiency is attained but at the price of inequality in profits in case of heterogeneous players, whereas asymmetric institution is designed in such a way that in case of heterogeneous players, all the players get the same payoffs. Initial endowment of resource is the same in all the treatments. The payoffs in the four treatments are listed in Table 2.1. The results indicate a relatively strong aversion for inequality in the final payoffs of the game: 40% of low type players impede the emergence of the symmetric institutional setting, and 45% of players in the homogenous setting reject the asymmetric institution.

	Symmetric institution	*Asymmetric institution*
Homogenous players	*c=20* *π=40*	*c=20, c=8* *π (c=20)=32; π (c=8)=44*

Heterogeneous players	$c=20$ $\pi_h=45, \pi_l=30$	$c_h=20, c_l=8$ $\pi_h=\pi_l=36$

Table 2.1. Contribution to and payoffs from public good in the different treatments. Source: adapted from Kube et al. (2015)

Janssen et al. (2011) analyse four conjectures related to the individual contributions to common-pool resource such as irrigation infrastructure, where access to the resource is asymmetric across the players. The main ideas that the authors test are that in an asymmetric situation, upstream players will exploit their position, and that as a consequence, downstream players will significantly reduce their contribution. To test these conjectures, the authors formulate a n-player game. In the game players have to decide first on how much to invest in the public infrastructure, second on the rate of extraction of the resource. The production function is set in such a way that positive returns from water are only possible when cooperation emerges. The provision of the resource is a s-shape production function: with both increasing and decreasing. Players are positioned in a network so that access to the resource is asymmetric. The main result of interest here is that individual contributions of tail users are negatively related to the amount of resource abstracted by head users, hence indicating the importance of equity in the appropriation of the resource.

Anderies et al. (2013) analyze how coordination and investment in a public good is affected by asymmetry in the access to the resource, and by uncertainty in earnings. The experiment description follows. The game is a public good game where 5 players have to invest in a collective infrastructure, which it delivers water to all the players. There are 20 rounds, the first 10 rounds have a stable environment, and the subsequent 10 rounds have a variable water availability. Each round is composed by three stages: the first is the communication stage, in which players can exchange messages; in the second stage, players decide on how much to invest in the common infrastructure. Finally in the third stage individual appropriates the resource. Production of infrastructure is linear in effort invested, but water and benefits have an *s* shape function. Players are along a network, and so that there is an order in which players can appropriate the resource. Water is scarce, the sum of the individual optimal amount of water is less than the total availability. Thus, if first users employ the optimal amount of water, not enough water is left for the next players. This setting enables the authors to assess the complex relation among the geography of the environment (the network), the investment in the infrastructure, and the variability in the environment. The result of interest here is the relation between inequality and investment. It is shown that investment of downstream players increases with their earnings, which are then determined by the restraint of the upstream players. This indicates that players are conditional co-operators. The second interesting result is that uncertainty and inequality interact: initially is relatively more important determinant in a stable environment, where most likely the link between investment and earning is clearer and not affected by external factors.

2.5 Lessons from the literature review

While some national implementations were already in place, the 2014-2020 CAP reform suggests the potential of a collective approach toward biodiversity conservation and natural resource management. Quite interestingly, in E-R the development of irrigation water infrastructures have been for long incentivized the coordination the cooperation among farms with measures that have clear collective conditionally constraints in the form of MPR.

In the literature review I focus on three main aspects: the AB, on the rationale for setting MPR, and on distributional issues. Three lessons from the literature review:

First, using AB schemes is an effective way to deal with biodiversity conservation in rural landscapes (Albers et al., 2008; Drechsler et al., 2010; Wätzold and Drechsler, 2014). However multiple equilibriums could exist, and communication helps agents to coordinate their actions to select the social optimum outcome of the game (Banerjee et al., 2014; Parkhurst and Shogren, 2007; Parkhurst et al., 2002). This is an important result, since in contrast to the international arena there is plenty of anecdotal evidence of repeated interactions and communication within rural community. The other factors that facilitate the coordination of players are experience in "playing" (Parkhurst and Shogren, 2007), the availability of information regarding others' choices (Banerjee et al., 2014), the limited size (small) of the groups (Banerjee et al., 2012).

Second, coordination and cooperation with respect to some resource management is profitable for the farmers themselves (Cong et al., 2014; Epanchin-Niell and Wilen, 2014). Moreover, theoretical (Black et al., 1993; Brau and Carraro, 2011; Carraro et al., 2009; Rutz, 2001) and empirical (Kesternich, 2015; McEvoy et al., 2014, 2015) analyses show that the imposition of a MPR is an instrument that helps to improve the coordination and the cooperation among players, when environmental protection exhibits different degrees of non-rivalry and non-excludability. This can become important for policies that take into account the fact that at least some of the environmental protection actions that is incentivized benefit in a public good setting the farmers themselves. The literature that has been reviewed however does not explicitly address the design of financial incentives schemes. Moreover the agricultural economics literature on the topic shows the relevance of a collective approach, but do not deal with the stability of the potential players cooperating (Cong et al., 2014; Epanchin-Niell and Wilen, 2014). Thus such a literature does not address the potential mismatch between efficiency (or profitability) and stability of such arrangements.

Third, bargaining and the resulting distribution of benefits matter, even though such a topic have been largely ignored (Segerson, 2013). In addition to a dedicated literature (Anderies et al., 2013; Janssen et al., 2011; Kube et al., 2015; Marchiori, 2014), distributional considerations and bargaining issues emerge as cross-cutting issue from other papers (Kesternich, 2015; McEvoy et al., 2015; Wätzold and Drechsler, 2014). Benefits distribution is often suggested as potential impediment to cooperation, and thus the distributional effects of policy incentives seems to be a key element to account for.

Together these three points highlight the fact that an ex ante estimation of the effect of collective conditionality constraints on the stability of the cooperation and on the distribution of the benefits might be useful for the design of agricultural policy aimed at natural resource management.

3 Modelling collective conditionality constraints in rural policies: the effect on the formation of coalitions

3.1 Introduction: stability concepts and section overview

In the current section I analyse how the stability and thus the ultimate formation of a coalition of people (farmers) cooperating is affected by agricultural policies. In section 3.2 I focus on public good provision. More specifically I analyse a situation where the actions subsidized by the policy positively affect the utility of the entire population of the farmers, without the possibility that these benefits are excluded from being enjoyed by those non providing efforts. I assess the effect of a homogenous payment, and of a heterogeneous payment. I use the term "heterogeneous payment" to refer to a payment that discriminates between those players that cooperate from those who do not. In section 3.3 I investigate the effect of a subsidy on the formation of a club. The idea is that farmers can either exploit groundwater resource, or build a collective reservoir. The goal of the regulator is to reduce the pressure on groundwater resource by promoting the construction of reservoirs. The analysis applies concepts and results derived from previous studies (Pauly, 1970, 1967; Sorenson et al., 1978) to assess when and how a regulator can subsidize the club (the collective reservoir) to pursue its goals. In section 3.4 I reformulate a standard AB model in terms of CGT to assess the necessary subsidy to ensure that the core of the game is non-empty. A numerical application parameterizes the model on data coming from E-R.

The first stability concept that I present is the internal/external stability concept, which has been used in a number of papers dealing with public good type of environmental issues, like e.g. the number of country ratifying IEAs (Barrett, 2006, 1994; Carraro and Siniscalco, 1993; Carraro et al., 2009; Finus and Rübbelke, 2013) and voluntary agreement among firms on environmental issues (Ahmed and Segerson, 2011; Brau and Carraro, 2011; Segerson, 2013, 2013). The basic idea is a mix of CGT and NCGT. More specifically, it is assumed that there is a number of players that cooperate, a coalition, whose members decide on action to undertake taking into consideration the wealth of the whole coalition. In contrast, the players outside the coalition, the free-riders, maximize their own benefits, neglecting the welfare of both the coalition and of the other free-riders. Since we are in a public-good type of economic structure, actions of any player positively affect the welfare of the other players, and thus there are incentives to free-ride. Call $\pi_m(s)$ and $\pi_f(s)$ respectively the profits for a member of the coalition and of a free-riders in case the coalition is of size *s*. The coalition is self-enforcing, or *stable*, is an equilibrium of the game, in case nobody has incentives to leave it, nobody has incentives to join it. In mathematical terms:

- the internal stability condition is defined by: $\pi_m(s)\geq \pi_f(s-1)$, thus profits for a member are higher than the profits that one can get by withdrawing from the coalition (which then becomes smaller).
- the external stability condition is defined by: $\pi_f(s)\geq \pi_m(s+1)$ which means that profits for non-members, when the coalition is of size *s,* are higher than the profits of a member when the coalition increases by one.

A useful specification of the two stability conditions is the stability function, used for instance by (Carraro et al., 2009): $Z(s)= \pi_m(s) - \pi_f(s-1)$. The stable coalition s^* is then the largest integer smaller than *s* where *s* is characterized by $Z(s)=0$ and $Z_s(s)<0$.

Since the focus on the public good, I will use this notion of stability for the first case study that is indeed on public good.

For the remaining two cases the economic structure of the game is relatively simpler, there are no spillovers across coalitions, or the value attributed to a given coalition depends only on its members and their behaviour. Thus in the other two case studies I rely on the standard setting of CGT and the use of the characteristic function (which perfectly fits the description of the cases). A few notes on CGT are needed. Call $\Gamma(N, v)$ a cooperative game. Let $\{1,2, \ldots, n\}= N$ be a group of farms working together (hereinafter, grand-coalition), such that $\{i\}$ ($i = 1, 2, \ldots n$) are the singleton coalitions. Call S the set of feasible coalitions in the game, call s and t two possible coalitions of N. Call $v(S)$ the characteristic function of the game, that attributes a value to any given coalition (Loehman et al., 1979). Further assume superadditivity: $v(N) \geq v(s) + v(t)$ with $s \cap t = \varnothing$ and $s \cup t = N$. A game is convex when characterized by the fact that the bigger the coalition, the more is profitable for players to join it, leading to the so-called snowball effect. Mathematically: the game is convex if:

$$v(S \cup \{i\}) - v(S) \leq v(T \cup \{i\}) - v(t), \forall S \subseteq T \subseteq N \setminus \{i\}, \forall i \in N$$

The "core" of a cooperative game defines the set of rationally acceptable worth distribution shares, u_i, and it is defined by the following system of disequations (Gillies, 1959):

(3.1) $u_i \geq v(\{i\}) \quad \forall i \in N$

(3.2) $\sum_{i \in S} u_i \geq v(S) \quad S \subseteq N$

(3.3) $\sum_{i \in N} u_i = v(N)$

Equation (3.1) represents the so-called individual rationality constraint: it states that the share distribution of a given player cannot be lower than he or she could achieve for himself while being a singleton. Equation (3.2) is the group rationality constraints, and it means that members of a coalition should get in the grand-coalition at least what they could get by withdrawing from it. Finally equation (3.3) is the efficiency constraints: the entire worth attributed to the grand-coalition should be distributed among its members.

Since the core is a set of disequation, it can include a number of possible points that legitimately can be used to share the grand-coalition worth, but it can also be empty. Bondareva e Shapley independently found the necessary and sufficient conditions for the non-emptiness of the core, based on the proof of the dual linear programming theorem (Shapley, 1967). Moreover the convexity of a game is a sufficient condition for the non-emptiness of the core (Shapley, 1971). These conditions imply that the superadditivity of the game is not sufficient for the non-emptiness of the core.

The non-emptiness of the core means that the grand-coalition worth is relatively small with respect to the sub-coalition, so that it is not sufficient to satisfy all the claims that are made by the coalitions. In such a case, someone will find profitable to withdraw from the grand-coalition and act non-cooperatively, even though the grand-coalition represents a pareto improvement with respect to the other player partitions. A simple example clarifies it. Imagine a symmetric game (where $v(s)=F|s|$) with 3 farms 1, 2, 3 with characteristic function $v(1)=v(2)=v(3)=0$, $v(f,z)=B$, and $v(1,2,3)=T$ with $T>B$.

Observe that the game is superadditive since $v(1,2,3)> v(f,z) + v(i)$. Core allocation requires that $u_1+u_2 \geq B$, $u_1+u_3 \geq B$, $u_2+u_3 \geq B$. Adding up leads to $2(u_1+u_2+u_3) \geq 3B$, Finally using the efficiency constraints of the core, equation **(3.3)**, we can write $2T \geq 3B$ or $T \geq 3/2B$. It is easy to show that in case we had $v(1,2) \neq v(1,3) \neq v(2,3)$ and $B> v(1,2),v(1,3),v(2,3)$ we had a non-empty core in case $2B> v(1,2)+v(1,3)+v(2,3)$. Thus non-emptiness of the core demands a stronger requirement than superadditivity. This will be important for the design of policy measures aimed at incentivizing collaboration among players.

3.2 Public good

3.2.1 Basic setting

I start from a standard model used for instance by Barrett (2006). I assume *N* homogenous players, farmers. The profits for a single player are given by:

(3.4) $$\pi_i = bL - \frac{1}{2} k l_i^2$$

where l_i is the land allocated to environmental conservation by farmer *i*, *L* is the total amount of land dedicated to environmental conservation in the landscape: $L = \sum_i l_i$; *b* and *k* are positive parameters of respectively benefits and costs. Interpret *k* as the opportunity costs of non-allocating land to conservation goals, like e.g. farming productivity. Equation (3.4) entails that benefits depend on actions that cannot be totally controlled by the individual farmers, whereas costs are.

In a non-cooperative setting, any farmer maximizes his own benefits, taking for given the choices of the other farmers. If all the farmers behave non-cooperatively they maximize:

(3.5) $$\max_{l_i} \pi_i = b\left(l_i + \bar{L}_{-i}\right) - \frac{1}{2} k l_i^2$$

where subscript *–i* indicate the sum of land allocated to conservation by all the players excluding player *i*, and the bar over variables indicate that is considered fixed. First order conditions yields: $l_i = \frac{b}{k}$. Since players are homogenous we have that: $L = \frac{bN}{k}$. Social optimum would require instead that players take the decision on l_i maximizing the social benefits, thus they decide the level of l_i taking into account the benefits accruing to all the players, equalizing global marginal benefits to individual marginal costs, leading to $l_i = \frac{bN}{k}$ and $L = \frac{b}{k} N^2$. Observe that the non-cooperative setting leads to an inefficient outcome, where the extent of land allocated to conservation is N-times lower than at the social optimum.

Is it possible that cooperation or at least partial cooperation emerges in this setting? Such a question is answered by formulating a two-stage game setting and solving it by backward induction. In the fist stage players choose whether to cooperate or not. In the second stage, players allocate land to conservation goals. Thus the decision of cooperation in the first stage depends on cost and benefits that are decided in the second stage. A group of players cooperate, i.e. they decide on l_i taking into account the benefits of the coalition (not of all the population of the players), whereas non-members play non-cooperatively (free-ride) with respect to both the other players and to the coalition. Thus the game mixes elements of both CGT and NCGT. Call s the size of the coalition. In the second stage, members of the coalition (subscript m) obtain profits according to:

$$(3.6) \quad \pi_m = b\left(sl_m + \left(N-s\right)l_f\right) - \frac{1}{2}kl_m^2$$

Differentiating equation (3.6) with respect to l_m yields $l_m = \frac{sb}{k}$ and hence $L_m = \frac{b}{k}s^2$. The individual free-riders (subscript f) choices do not change with respect to the non-cooperative setting we have previously seen, thus we have: $l_f = \frac{b}{k}$ and $L_f = \frac{b}{k}\left(N-s\right)$. So total allocated land to environmental protection is:

$$(3.7) \quad L = \frac{b}{k}s^2 + \left(N-s\right)\frac{b}{k} = \frac{b}{k}\left(s^2 + N - s\right)$$

Now I analyse the first stage of the game, or namely whether is profitable for a player to join the coalition, and what is the resulting stable coalition by using the stability function: $Z(s) = \pi_m(s) - \pi_f(s-1)$. By introducing (3.7) and l_m into (3.6), we get the profits for a coalition member:

$$(3.8) \quad \pi_m\left(s\right) = b\left(\frac{b}{k}\left(s^2 + N - s\right)\right) - \frac{1}{2}k\left(\frac{b}{k}s\right)^2 = \frac{1}{2}\frac{b^2}{k}\left(s^2 + 2N - 2s\right)$$

Substituting **(3.7**) and l_f into **(3.4**) leads to the profits accrued to a free-rider:

$$(3.9) \quad \pi_f\left(s\right) = b\left(\frac{b}{k}s^2 + \left(N-s\right)\frac{b}{k}\right) - \frac{1}{2}k\left(\frac{b}{k}\right)^2 = \frac{1}{2}\frac{b^2}{k}\left(2s^2 + 2N - 2s - 1\right)$$

The stability function requires also the profits for a free-riders when the coalitions gest smaller by one, $\pi_f(s-1)$, which are given by (details are in the Appendix 7.1):

$$(3.10) \quad \pi_f\left(s-1\right) = b\left(\frac{b}{k}\left(s-1\right)^2 + \left(N-s+1\right)\frac{b}{k}\right) - \frac{1}{2}k\left(\frac{b}{k}\right)^2 = \frac{b^2}{k}\frac{1}{2}\left(2s^2 - 6s + 2N + 3\right)$$

Now substitute $\pi_m(s)$ and $\pi_f(s-1)$ in the stability function and set it equal 0 to find that:

$$Z\left(s\right) = \pi_m\left(s\right) - \pi_f\left(s-1\right) = 0$$

$$s^2 + 2N - 2s = 2s^2 - 6s + 2N + 3$$
$$s^2 - 4s + 3 = 0$$
$$s^* = 3$$

The other solution, $s=1$, is ruled out by the second condition, since $Z_s(1)<0$. Thus the stable coalition in such a setting is 3 irrespectively on the total population of agents N and on parameter levels.

3.2.2 Effectiveness of a collective approach

Now imagine a regulator that is interesting, for reasons not explicitly modelled, in the extent of land allocated to environmental protection (L), and set an AEP that is offered to farms whether they allocate land to such a purpose. The structure of the problem is similar to the analysis of ancillary benefits from climate change protection (Finus and Rübbelke, 2013).

By introducing a homogeneous AEP (p), individual profits become:

$$\pi_i = bL + pl_i - \frac{1}{2}kl_i^2$$

Proceeding as in the previous section, in a non-cooperative setting we get $l_i = \frac{b+p}{k}$ and $L = \frac{(b+p)}{k}N$ while the social optimum is given by: $l_i = \frac{bN+p}{k}$ and $L = \frac{bN+p}{k}N$. The payment increases the extent of land allocated to conservation goals, but it does not solve the free-riding problem, since the social optimum is still higher than the nash-equilibrium. Note that setting $p=0$ leads to the problem that has been previously described.

Now assume that the regulator can discriminate between members and non-members of the coalition, and thus he can set a payment p_m for coalition members and a payment p_f for free-riders (note that a homogenous payment would simply be described by setting $p_m = p_f$). The problem is still set in two stages, and we get that a member of a coalition allocates land by solving the following maximization problem:

$$\text{(3.11)} \quad \max_m \pi_m = b\left(sl_m + (N-s)l_f\right) + p_m l_m - \frac{1}{2}kl_m^2$$

FOC yield: $l_m = \frac{bs+p_m}{k}$ and $L_m = \frac{bs+p_m}{k}s$, while for non-members: $l_f = \frac{b+p_f}{k}$ and $L_f = \frac{b+p_f}{k}(N-s)$. Total land in the area allocated to conservation is:

$$L = \frac{bs+p_m}{k}s + \frac{b+p_f}{k}(N-s).$$

In the fist stage I again assess the size of the stable coalition. Profits for members of the coalition are:

$$\pi_m = b\left(\frac{bs+p_m}{k}s + \frac{b+p_f}{k}(N-s)\right) + p_m\frac{bs+p_m}{k} - \frac{1}{2}k\left(\frac{bs+p_m}{k}\right)^2$$

Whereas for a free-riders are:

$$\pi_f = b\left(\frac{bs+p_m}{k}s + \frac{b+p_f}{k}(N-s)\right) + p_f\frac{b+p_f}{k} - \frac{1}{2}k\left(\frac{b+p_f}{k}\right)^2$$

Profits for free-riders when a coalition is smaller by one member are:

$$\pi_f\left(s-1\right)=b\left(\frac{b\left(s-1\right)+p_m}{k}\left(s-1\right)+\frac{b+p_f}{k}\left(N-s+1\right)\right)+p_f\frac{b+p_f}{k}-\frac{1}{2}k\left(\frac{b+p_f}{k}\right)^2$$

To continue, for simplicity let normalize profits to cost, setting *k=1*. The size of the stable coalition is again found by setting the stability function to 0. After some steps (which you can find in Appendix 7.2), it is shown that the size of the stable coalition is given by:

$$s^*=2+\frac{1}{b}\sqrt{b^2+\left(p_m^2+2bp_m-p_f^2-2bp_f\right)}=2+\sqrt{1+\frac{p_m^2}{b^2}+\frac{2p_m}{b}-\frac{p_f^2}{b^2}-\frac{2p_f}{b}}$$

Thus the size of the stable coalition increases with the difference between the payment attributed to the coalition, and the payment attributed to the free-riders. Note that by setting $p_f=p_m$ we are in the homogenous payment case; further note that such a policy scheme does not affect the size of the stable coalition since it is equal to $s^*=3$. In Figure 3.1we can observe the profits for coalition members and for free-riders in two policy scenarios.

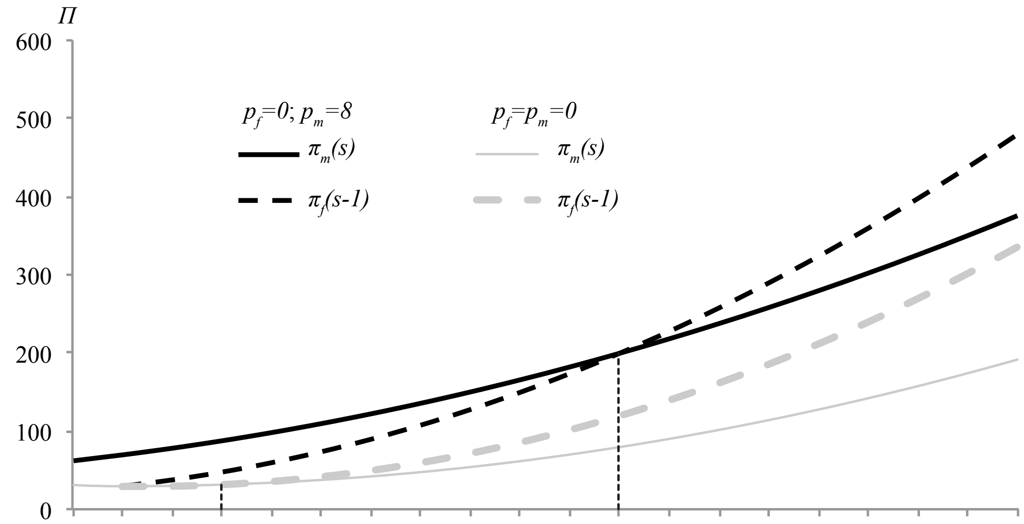

Figure 3.1. Profits for coalition members $\pi_m(s)$, and free-riders $\pi_f(s-1)$ in two AEP scenarios. Black curves have $p_f=0$ and $p_m=8$; whereas grey curves are the results of $p_f= p_m=0$. In both cases $N=30$, and $b=1$. The stable coalitions in the two cases are also indicated: $s^*=3$ and $s^*=11$.

I now analyse the effectiveness of the payments; recall that total amount of land allocated to conservation, normalizing by setting *k=1*, is given by: $L=\left(bs+p_m\right)s+\left(b+p_f\right)\left(N-s\right)$. Consider for simplicity only two cases: first when $p_f=0$ and $p_m>0$, and a second case where $p_f=p_m$. In the first case we have that $s^* = 3 + \frac{p_m}{b}$. Substituting s^* into L we get that the total amount of land allocated to conservation is given by: $L^e = 6b + 8p + \frac{2p^2}{b} + bN$ where superscript e denotes the heterogeneous payment, and where I drop the subscript m and f so to be compared with the next case. In the second case we have: $L^o = bs^2 + bN + pN - bs$ Substituting $s^*=3$ we get: $L^o = 9b + bN + pN - 3b$

Observe that L^e is related quadratically to p, while L^o is linearly related to p. Thus For any level AEP, when is convenient to incentivize only the coalition, or to incentivize also the free-riders? Or in other word, when $L^e > L^o$? Simple algebra yields (see Appendix 7.3):

(3.12) $\hat{p} > \frac{1}{2} b(N - 8)$

Equation (3.12) gives some insights on the range of parameters that make the discrimination between coalition and free-riders effective. When the relevant population is relatively small ($N<8$) the rhs of equation (3.12) is negative, and thus for any level of payment is convenient (gives higher extent of land allocated to conservation goals) to incentivize only the coalition. Moreover, the higher the benefits (b), and the population, the higher the level of *AEP* for which again is convenient to solely incentivize the coalition. By substituting equation (3.12) into L^o we get the critical level of L above which, for any level of p, the restriction of the payment to the coalition members yields more total provision of conserved land:

(3.13) $\hat{L} = b\left(6 + \frac{1}{2}N^2 - 3N\right)$

Equation (3.13) indicates that if the regulator requires a level of total land allocated to conservation goals higher than $\hat{L}$, it is more cost effective to target only the members of the coalition, whereas, for lower levels an indiscriminate payment is more effective. $\hat{L}$ is clearly increasing in b. Taking first derivative of equation (3.13) with respect to N, shows that $\hat{L}$ is increasing in N when $N > 3$. All together this information suggest that a collective approach is an option worth exploring especially when both the population of farmers, and the benefits accrued to them in term of public goods are relatively small, and when the environmental goal is relatively high. A numerical example, showing the critical level $\hat{L}$ is depicted in Figure 3.2.

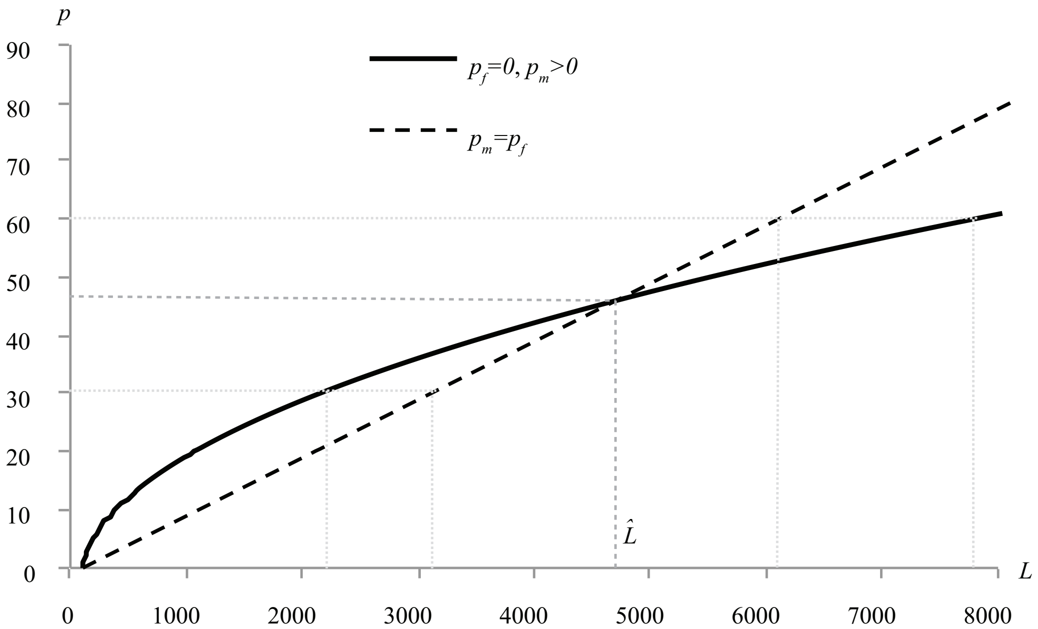

Figure 3.2. Relationship between p and L for $N=100$, and $b=1$. The critical level of L is, simply applying equation (3.13), is $L= 4706$.

3.2.3 Minimum Participation Rules associated with Agri-Environmental Payment

A relevant issue in the IEA literature is the possibility to use a MPR as a coordination device. In this section I analyse whether such a MPR associated with an AEP is an equilibrium of the game. First observe the issue graphically. In **Figure 3.1** it is possible to observe how setting an AEP that discriminates between members of the coalition and free-riders leads to an increase in the size of the stable coalition (that in the numerical example represented in the figure it passes from $s*=3$ to $s*=11$).

I now consider the case where a positive discriminating *AEP* is linked to a MPR set on a minimum number of players (t). Consider the simple case where no payment is offered ($AEP=0$) in case $s<t$. Is the coalition of size t stable? Any coalition of size $t<s*$ is clearly unstable since it would be more profitable to reach size s*, which is stable by definition. Now I describe the situation in case $t>s*$.

Call π^p the profits for farmers in case of $AEP>0$ when (only) the coalition gets the AEP ($p_m>0$ $p_f=0$); no superscript indicate the situation where no AEP is offered ($p_m=p_f=0$). The external stability condition is met since we are in situation where $s>s*$ in which for sure $\pi^p{}_f(s)\geq \pi^p{}_m(s+1)$. Moreover, recall that the a coalition is internally stable if $\pi_m(s)\geq \pi_f(s-1)$. Setting a MPR on the payment means that the coalition of at least t gets the payoff augmented by the AEP: $\pi_m(t)= \pi^p{}_m(s \geq t)$. When $s=t-1$ we are back to the case where there is not AEP, in which profits for the coalition members are given by $\pi_m(s-1)$ and for free-riders are $\pi_f(s-1)$. The coalitions $s>t$ are thus stable when $\pi^p{}_m(s \geq t) > \pi_f\,(s=t-1)$. This is shown in Figure 3.3.

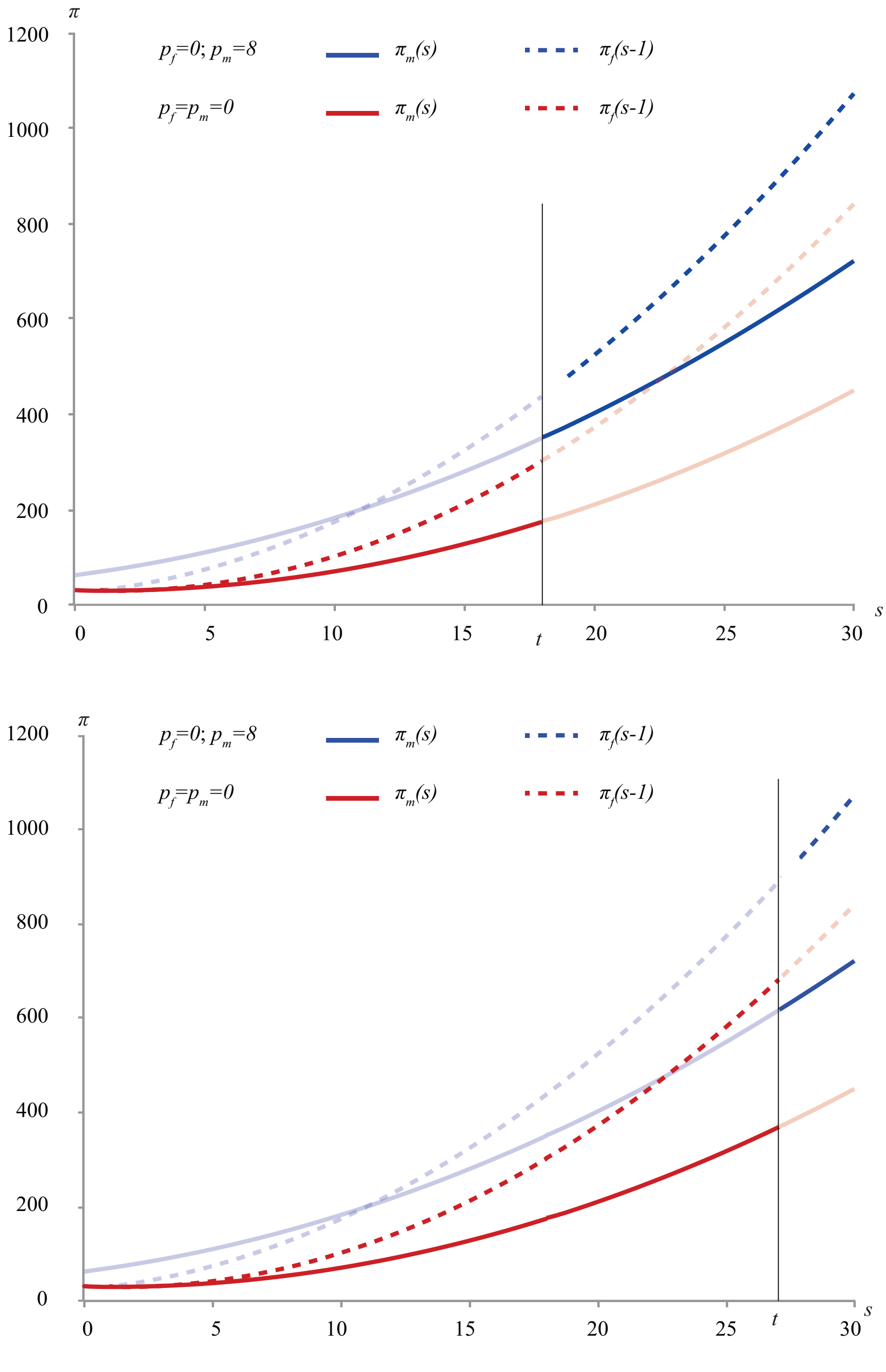

Figure 3.3 Effect of MPR associated to an AEP. In red are indicted profits for coalition members and free-riders when $p=0$, in blue profits for coalition members and free-riders when $p>0$. In the upper graph $\pi^p{}_m(s \geq t) > \pi_f\,(s=t\text{-}1)$, thus the coalition $s=t$ is stable. In the bottom graph t $\pi^p{}_m(s \geq t) < \pi_f\,(s=t\text{-}1)$, thus the coalition of size $s=t$ is not stable.

By setting $k=0$, and $p_f=0$, profits for a coalition member are given by (Appendix 7.4):

$$\pi_m^p(t) = \frac{1}{2}b^2t^2 + btp_m + b^2(N-t) + \frac{1}{2}p_m^2$$

whereas for free-riders are

$$\pi_f(t-1) = \frac{b^2}{2}\left(2t^2 - 6t + 2N + 3\right)$$

Setting $\pi^p_m(s) > \pi_f(s-1)$ yields:

$$t < 2 + \frac{p}{b} + \sqrt{4 + 8\frac{p^2}{b^2} + 16\frac{p}{b}}$$

which shows there is a maximum critical value of t, above which the coalition set by MPR is no-longer stable. Such a maximum critical value is increasing in the ratio p/b.

In term of effectiveness, the imposition of MPR, within the range of values that have been just found, means that an increase in the total land conserved can be achieved by simply increasing the MPR, rather than increasing the payment. Thus, with a MPR the discriminating payment shows to be cost-effective at levels of L lower than in the one found in the previous section (Figure 3.4).

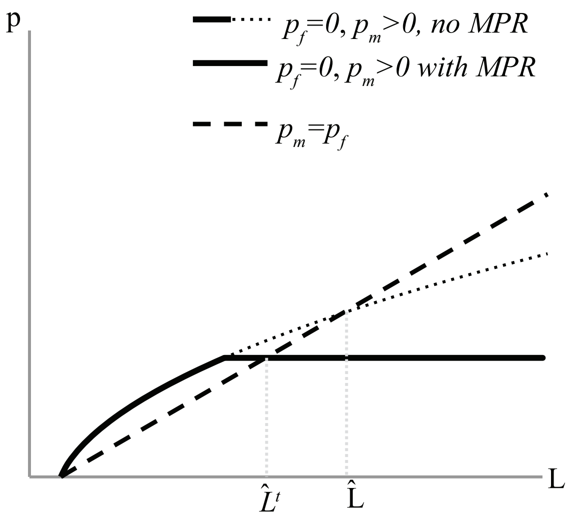

Figure 3.4. Relationship between p and L for $N=100$, and $b=1$, with and without MPR.

3.3 Club goods

3.3.1 Basic setting

Club goods where first investigated by Buchanan (1965) and since they have been extensively analysed (Sandler, 2013). Applications of club and CGT in the agricultural economics literature include the analysis by e.g. Mérel et al. (2015) and Sexton (1986) which apply CGT to the formation of agricultural cooperatives. More from an environmental point of view, van't Veld and Kotchen (2011) applies club theory to "green" clubs. Early application of CGT to club theory is due to (Pauly, 1970,

1967) which finds that when multiple club can form, and in case of homogenous players, the core of the economy is non-empty only in case the population of players can be evenly partitioned in a number of clubs characterized by the same (optimal) size and no-one remains outside. Calling N the population of players, s^* the optimal size of the club, and S the number of clubs that are formed, the number of club is given by: $N/s^*=S+r$. The core is non-empty if $r=0$.

Recall that a club has two dimensions: the number of members (n-size, hereinafter) and the size of the facility (q-size, hereinafter). The optimal *absolute* club is when both dimensions ensure the maximum average benefits: $Q^*(s^*)$. Recall however, that in some cases the population of players can be not regarded as a variable, in such a case we have only one dimension of the club, the size of the facility, given a fixed population of players: $Q^*(N)$.

The next part gives some basic results on club due to Sorenson et al. (1978). These standard results will be used next to investigate how and when a regulator can use subsidy on the membership fees club to achieve some exogenous policy goals. A list of the relevant variables used in the model formulation is in Table 3.1.

Symbol	**Explanation**
N	Population of players, fixed
s	Club n-size, variable
s^*	Optimal club n-size
$Q^*(N)$	Optimal club q-size given a fixed population of players
$Q^*(N, \alpha)$	Optimal club q-size given a fixed population of players and subsidy rate
$Q^*(s^*)$	Optimal absolute club, in both dimension (q-size and n-size)
MC	Marginal cost, no policy
$MC(\alpha)$	Marginal cost, with policy
AC	Average cost, no policy
$AC(\alpha)$	Average cost, with policy
$AC(Q^*(s^*))$	Minimum average cost

Table 3.1. List of relevant variables and explanations that are used in the current section

Assume that the individual demand for the club is linear and takes the form:

(3.14) $f(q_i) = -aq_i + b$

The aggregated demand function (given by the horizontal addition of the individual demand function, which is simply a rotation of the individual demand function) is thus given by:

(3.15) $F(Q) = -\frac{a}{s}Q + b$

Assume the cost function is the cubic function, which then exhibits both decreasing and increasing AC and MC.

(3.16) $K = \frac{1}{3}cQ^3 - dQ^2 + eQ$

where $Q = \sum_i q_i$ and water is distributed when the marginal value of the water is equal across the farmers (thus equal distribution since players are homogenous): $Q = \sum_i q_i = sq_i$

The marginal cost function is:

$\partial K / \partial Q = cQ^2 - 2dQ + e$

Holding constant the n-size, the q-size is given by the point where the aggregated demand intersects the marginal cost function. However, the optimal club size is the one who maximizes benefits for members, accounting for both club dimensions, since members can effectively exclude non-members from entering the club. Thus optimal club is found by maximizing:

$$(3.17)\quad \max_{s,q_i} \frac{\Pi}{s} = \pi_i = f\left(q_i\right) - \frac{1}{s} K\left(sq_i\right) = -\frac{1}{2} aq_i^2 + bq_i - \frac{1}{s}\left(\frac{1}{3} cs^3 q_i^3 - ds^2 q_i^2 + sq_i\right)$$

Two are the first order conditions:

$$\partial \pi_i / \partial s = 0 \Rightarrow -\frac{2}{3} cq_i^3 s + dq_i^2 = 0$$

$$\partial \pi_i / \partial q_i = 0 \Rightarrow aq_i + b - cs^2 q_i^2 + 2dsq_i = 0$$

Which after some steps yields to (Appendix 7.5):

$$q_i^* = \frac{1}{a}\left(b - \frac{3d^2}{4c} - e\right)$$

$$s^* = \frac{6da}{4cb - 3d^2 - 4ce}$$

Note that:

$$Q^* = q_i^* s^* = \frac{3d}{2c}$$

Observe that the optimal q-size of the club is when the average cost function is at the minimum like in Figure 3.5 (Sorenson et al., 1978).[10]

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[10]Average costs is: $\bar{k} = \frac{1}{3} cQ^2 - dQ^2 + e$; minimum is given by: $\partial \bar{k} / \partial Q = \frac{2}{3} cQ - d = 0 \Rightarrow Q = \frac{3d}{2c}$

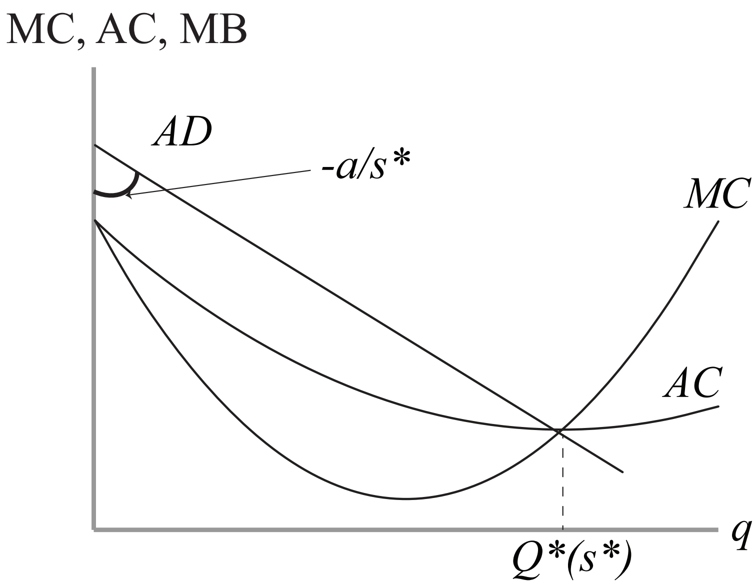


Figure 3.5. Optimal club n-size is given at the point of intersection of MC and AC (point A) which in turn determines the optimal q-size of the club.

There results are used to assess the effect of policy incentives on a club economy. Assume that the policy subsidize the club construction by covering a share of the cost, so that after the subsidy club members pay *αK(Q)* and the policy support is *(1-α)K(Q)* with *0<α≤ 1*. Thus equation (3.17) is transformed into:

$$\text{(3.18)}\ \max \frac{\Pi}{s} = \pi_i = f\left(q_i\right) - \frac{1}{s}\alpha K\left(sq_i\right) = -\frac{1}{2}aq_i^2 + bq_i - \left(\frac{1}{3}c\alpha s^2 q_i^3 - \alpha dsq_i^2 + \alpha eq_i\right)$$

Note that the optimal q-size of the club is not affected by the policy:

$$Q^*\left(\alpha\right) = q_i n = \frac{3\alpha d}{2\alpha c} = \frac{3d}{2c}$$

Instead, the optimal n-size of the club increases with increases in the membership fees, and thus a subsidy on the membership fees reduces the n-size of the club and it increases the intensity of the use of the club:

$$n^*\left(\alpha\right) = \frac{6\alpha da}{4\alpha cb - 3\alpha^2 d^2 - 4\alpha^2 ce} = \frac{6da}{4cb - 3\alpha\left(d^2 - 4ce\right)}$$

3.3.2 Application to water resources

Given the findings of the previous section, here I analyse how incentives set by the policy affect a club good economy. Imagine farms can either exploit groundwater resources using quantity $q_i^{g,*}$ and getting π^g_i. Alternatively they can build a collective rainwater-harvesting water reservoir which is a club good that delivers profits for $\pi_i(s)$. Farmers using ground water resource are $g=N\text{-}s$, The pressure on groundwater resource is $(N-s)q_i^{g,*}$. Further assume for simplicity that the individual exploitation of the aquifer has no externality on the other users, and thus also the club does not deliver positive spillovers on non-members of the club. Moreover, the goal of the policy is to reduce the amount of water abstracted from the aquifer. I only analyse the possibility that the policy can use subsidy, and cannot influence the rules of the club (cannot impose an open-access regime to the club).

3.3.2.1 A single club and no policy

Say for technical reasons only one reservoir can be built. First I describe what happens in the absence of policy. A club is formed only if $\pi_i(s) \geq \pi^g{}_i$. Thus, there exist a minimum size of club members for the club to be more profitable than exploiting groundwater resource (s^{min}). Three conditions can emerge, depending on the total population of farmers (N):

1) If the population of farmers is $N < s^{min}$, then no club is going to form and the whole population will exploit groundwater resource.
2) On the other hand, if the population of farmers is in between the minimum club size and the optimal n-size ($s^{min} < N < s^*$), the club that will form will be of size N and no farms will use ground-water resource.
3) Finally if $N \geq s^*$ the club will be of size s^* since club members will be effectively capable of excluding members beyond the optimal size and there are $N\text{-}s^*$ farms that exploit the aquifer.

All these conditions are depicted in Figure 3.6. Thus in case of a single club, given the policy objective of reducing ground-water abstraction, there is scope for policy intervention only i) in the first case ($N< s^{min}$) and ii) in the third case ($N \geq s^*$) if the size $N\text{-}s^*$ of farmers exploiting the aquifer is not considered enough from the policy viewpoint.

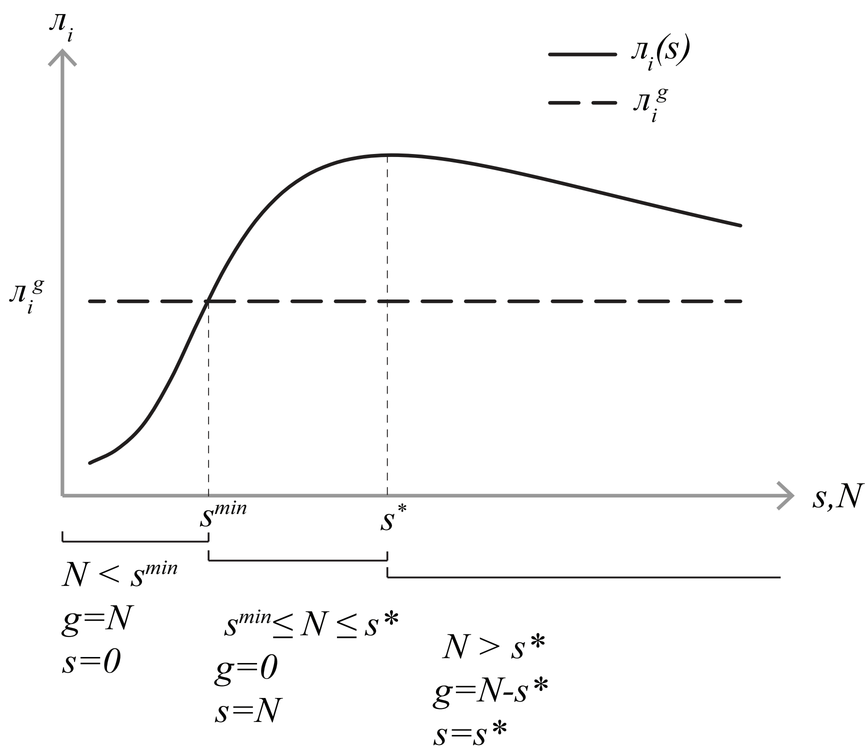


Figure 3.6. Farm profits from groundwater exploitation and from a reservoir (club).

3.3.2.2 Single club and Policy

As we have seen in the previous section, a subsidy causes a reduction in the optimal n-size of the club (and an increase in the profit, for any level of s). A policy causes also a reduction in the s^{min} so that the policy incentives can be used to reduce the amount of water abstracted from the aquifer, by incentivizing the club when, in the original case, $N<s^{min}$. The incentive should be then set so that the critical value of s for the club to become profitable is at the level of the farm population: $s^{\alpha,min}=N$. This is depicted in Figure 3.7.

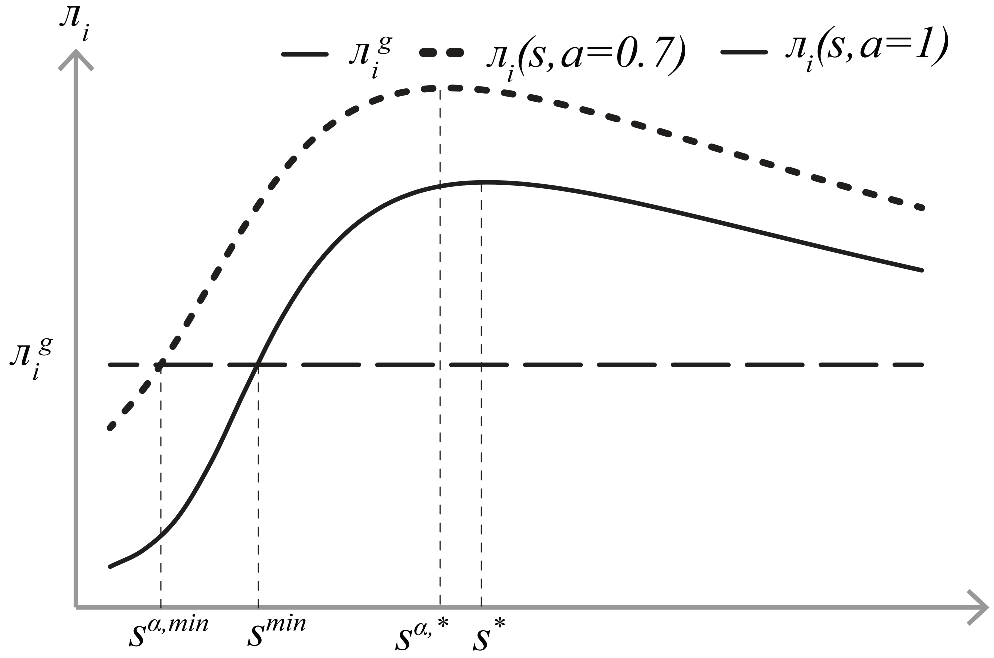


Figure 3.7. Profits from groundwater exploitation, and from reservoir construction in case of no policy (full curve) and in case of financial support (dotted curve). Optimal n-size of the club is reduced (from s* to $s^{\alpha,*}$) as well as the critical n-size of the club (from s^{min} *to* $s^{\alpha,min}$).

If we are in the case of $N \geq s^*$, and N-s^* is considered a too strong pressure on groundwater is possible to increase the ultimate size of the club by associating the incentive to a MPR on club n-size (t). As it was noted, indeed a simple subsidy on the reservoir construction cost actually decreases the optimal n-size of the club, and the membership rule of the club will prevent form other members to enter beyond the optimal n–size. Thus a simple subsidy would not achieve, in this condition, the desired goal. By setting a $t>s^*$ club members will accept new members to reach the level t, above which the n-size is no longer optimal, by definition, and no-one else will be accepted. Note however that for any level of α, there is a maximum level $t=t^{max}(\alpha)$ which is determined by the point of $\pi_i(s^*) \geq \pi_i(t)$, above which the club will shrink back to s^*. This is depicted in Figure 3.8.

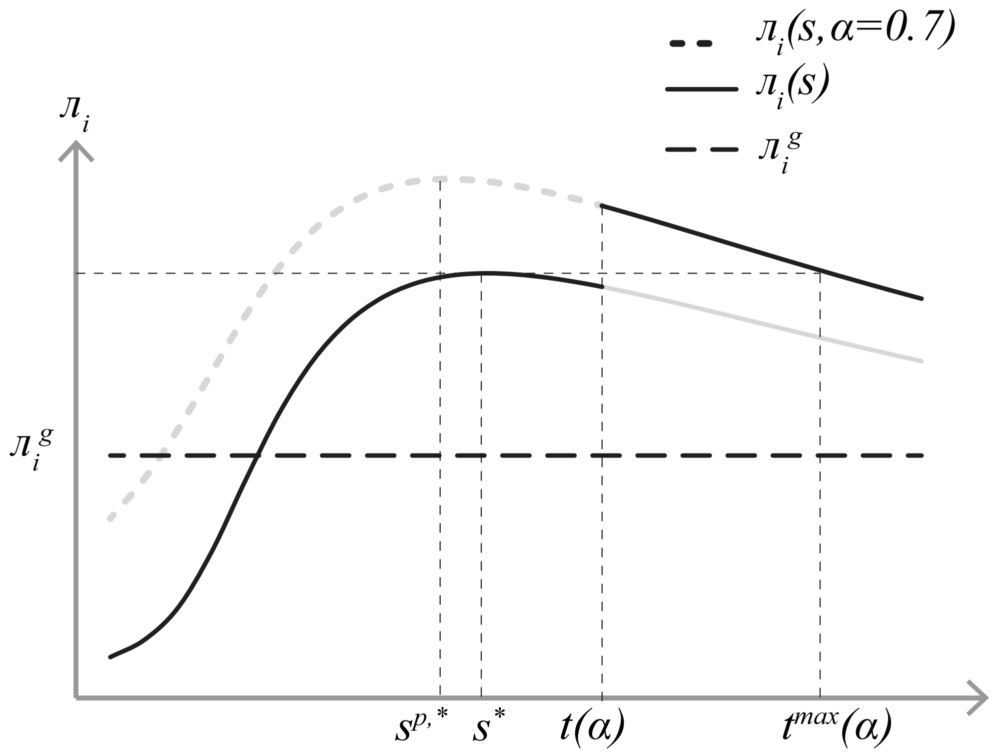


Figure 3.8. Profits from groundwater exploitation, and from reservoir construction in case of no policy (bold curve) and in case of financial support (dotted curve). Maximum t for a level of financial support is indicated by t^{max}.

3.3.2.3 Multiple clubs

What happens when the club number is not fixed or not limited? When is stable the club partition of the population of players?

Sorenson et al. (1978) link the shapes of the cost function and of the aggregate demand function to the non-emptiness of the core, and to the convexity of the game. Given a population level N (n-size of the club, fixed), the optimal quantity (q-size of the club, variable) is given by the point of intersection of the aggregated demand function (AD) with the marginal cost function (MC).

First, if the optimal quantity for the population N (thus $Q^*(N)$) is in the range where the MC is decreasing (up to point a in Figure 3.9, left), the game is convex (and thus the core is non-empty). Moreover, the core is still non-empty, even though the game is no longer convex, as long as the optimal quantity is in the range where the average cost function (AC) is decreasing (up to point b in Figure 3.9, right). In both cases, the result is that a single stable club formed by all population is going to form. The logic is the following. An increase in the number of players causes a rotation in the aggregated demand far away from the origin. The rotation continues up to the level of the aggregated demand of the entire population of the players (N), so for the population level N, $Q^*(N)$ is the maximum. Since we are in the area where the average cost is decreasing, any club of n-size smaller than N will have a average cost that is higher than the average costs at Q^*N. thus any club smaller than N will accept new members since an additional member will increase profits (decreasing the average cost) more than proportionally, ensuring the non-emptiness of the core.

When the optimal quantity is beyond the quantity that lead to the minimum average cost, all possible situation might emerge: the core might be non-empty, and also the game can be no longer superadditive. The main result of Pauly is still valid. If $N \geq 2S^*$ and N/s^* is an integer number, a system of multiple club is going to emerge.

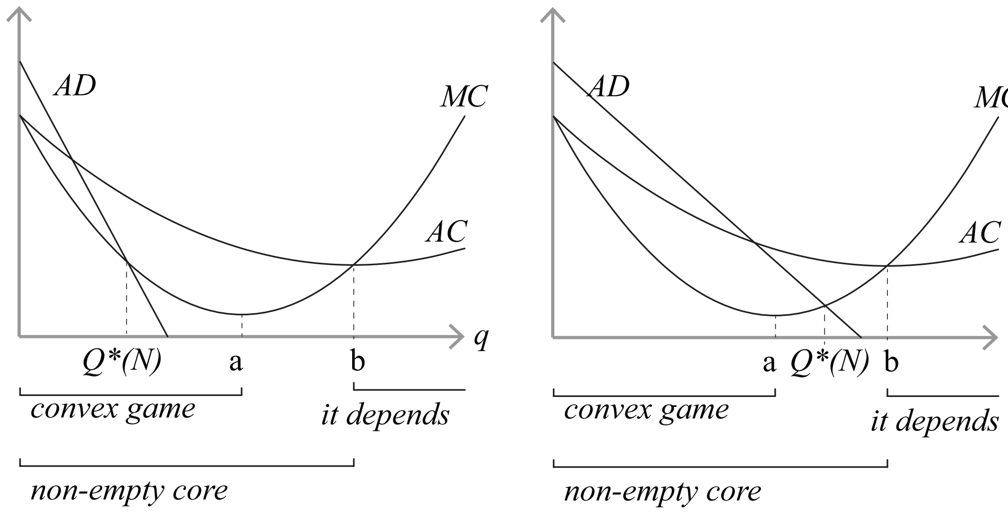


Figure 3.9. Left, Convex game. Given a population N, the optimal quantity *Q*(N)* is in the decreasing part of the marginal cost function (up to point a). Right, non-empty core. Given a population N, the optimal quantity *Q*(N)* is in the decreasing part of the average cost function (up to point b).

A relevant question, that I address here, is how to provide incentives in a middle case, namely when the population of players (farmers) is greater than the optimal s^* but lower than $2s^*$ so that a system of multiple clubs is not going to form since the core of the game is non-empty.

Two possibilities we have. First that the regulator provides a subsidy rate $(1-\alpha)$ up to the point where $s^*(\alpha) = N/2$. In such a case two clubs are going to form.

Second, the regulator can provide incentives associated with a MPR. The logic is depicted in **Figure 3.10**. Clearly even in this case the optimal q-size of the club is at the point of intersection (point *B* in **Figure 3.10**) between the aggregate demand and the marginal cost function reshaped by the subsidy, the curve $MC(\alpha)$, in Figure 3.10. As it was noted earlier, the subsidy does not affect the optimal q-size of the club, since the quantity that leads to the minimum average cost is not affected Thus there is the need to associate two additional constraints to the subsidy. First, the subsidy rate should be designed so that AC of the q-size of the club is equal or less to the minimum AC of the pre-subsidy cost function: $AC(Q^*(N, \alpha)) \leq AC(Q^*(s^*))$. Finally the MPR should be set at the level of the population of the players, to ensure that smaller group of players find profitable to accept new members up to the level of the entire population.

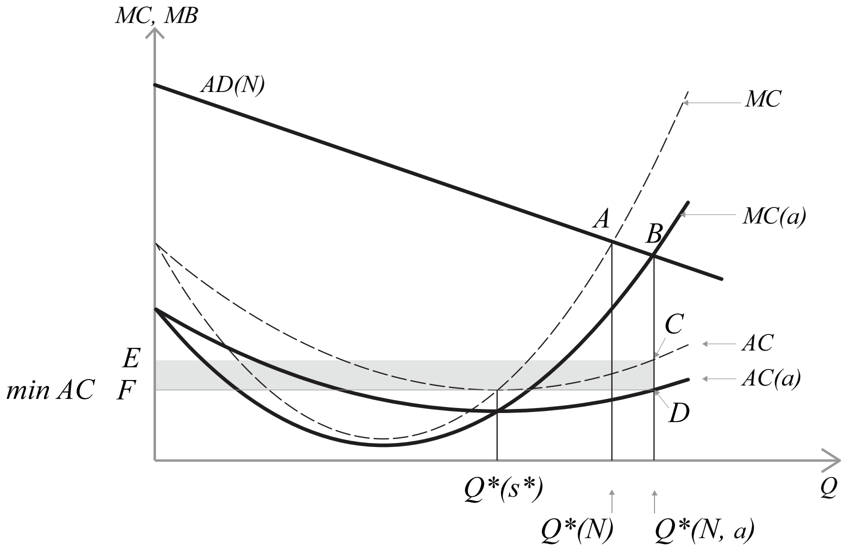


Figure 3.10. Setting of incentives to ensure non-emptiness of the core when $N>s^*$, and $N<2s^*$. The subsidy required for the core to be non-empty is represented by the grey rectangle defined by the points CDEF.

3.4 Private cost: Agglomeration Bonus

3.4.1 Model

In this section I reformulate a standard model on AB payment in terms of CGT. I then use the characteristic function to define the values of profits for coalitions, and then I analyse the conditions that enable the non-emptiness of the core. Assume three farms ($f=1,2,3$), with two parcels of land each characterized by different soil quality ($q=L,H$). Soil quality and farms are associated to different farming productivity ($y_{f,q}$) which I assume they are ordered as follow: $y_{1,L}< y_{1,H}< y_{2,L}< y_{2,H}< y_{3,L}< y_{3,H}$. Assume farms are spatially located in the landscape according to an adjacency matrix $a_{i,j}$. Further assume that farmers can contract parcels of land in an environmental policy scheme ($E_{f,q}=1$ if the farms participates, 0 otherwise) aimed at retiring land from agriculture in exchange for an AEP, so that the opportunity costs of the AEP is the farming productivity.

Any farm faces the following maximization problem:

$$(3.19)\quad \Pi_i = \max_{E_{f,q}} \sum_q \left\{ \left(1 - E_{f,q}\right) y_{f,q} + E_{f,q} AEP \right\}$$

s.t.

$$(3.20)\quad \sum_q E_{f,q} \le 1 \; \forall f$$

Thus any farm decides between business as usual and contracting a maximum of one parcel of land (equation (3.20)) under a conservation program that is rewarded by the AEP. The AEP is composed by two parts, namely a standard payment p and an AB which is a function of the number of adjacent neighbours that also contract parcels of land:

$$(3.21)\quad AEP = pE_{f,q} + AEP^{AB}\sum_{z\neq f} a_{z,f}E_{z,q}$$

Further assume that in case two players allocate adjacent land to conservation they get *b*, and in case three players allocate adjacent plots of land to conservation they get *t*:

$$(3.22)\quad AEP^{AB}\sum_{z\neq f} a_{z,f}E_{z,q} = \begin{cases} b \text{ if } \sum_{z\neq f} a_{z,f}E_{z,q} = 1 \\ t \text{ if } \sum_{z\neq f} a_{z,f}E_{z,q} = 2 \end{cases}$$

Now I write the structure of the problem in terms of CGT. Since I allow for side-payments (transferable utility), for simplicity call $B=2(p+b)$ and $T=3(p+t)$. Assume $a_{fH,zH}=1$, $a_{fL,fH}=1$ and $a_{i,j}=0$ otherwise (see Figure 3.11). In this context, alone each farm contracts the lowest quality land; moreover equations (3.20) implies that the AB is only rewarded in case farms collaborate, and that the AB is rewarded only if the high quality lands are contracted.

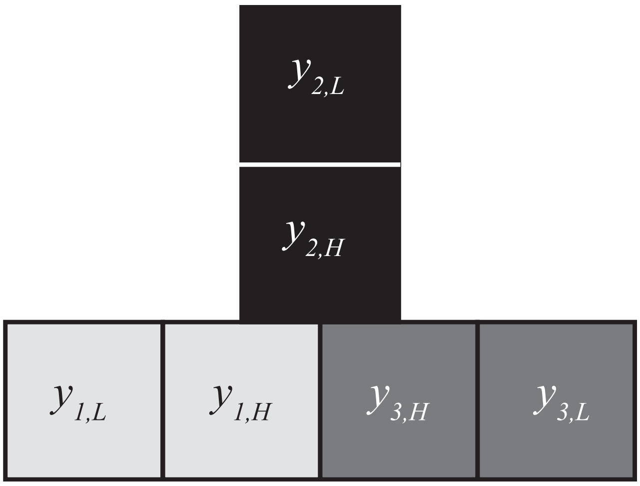


Figure 3.11. Location of farms and productivity

As singletons, farms simply compare the lowest farming productivity and the AEP and observe whether the scheme is profitable:

$$(3.23)\quad v(f) = y_{f,H} + \max\left(p, y_{f,L}\right)$$

Two-player coalitions observe whether the coordination rewarded by the AB is more profitable than acting non-cooperatively (according to equation (3.23)):

$$(3.24)\quad v(f,z) = \max\left\{B + y_{f,L} + y_{z,L};\ v(f) + v(z)\right\}$$

Clearly there are trade-offs between the standard payment *p* and the AB. The higher *p*, the higher the number of farms that as singletons enrols in the conservation programme. On the other

hands, the higher p, the higher is the level of B required to have two farms collaborate, since singleton payoffs are the opportunity costs of cooperating.
Finally if the grand coalition is formed gets:

(3.25) $v(1,2,3) = T + \sum_f y_{f,L}$

Continuing the reasoning, the higher p and B, the higher the level of T that is required for the core to be non-empty, so that the farms find a way to distribute the grand-coalition worth. Recall from section that superadditivity is not enough for a core to be non-empty. Applying this to the AB structure previously described implies that the grand coalition is stable if: $T + \sum_f y_{f,L} > \frac{1}{2}\left[v(1,2) + v(1,3) + v(2,3)\right]$. Thus the level of T required for the non-emptiness of the core is increasing in both p and B. Usually these policies are homogenous all over a relatively large heterogeneous area (like regional administration). What the CGT shows is that, in setting this type of payments, there are trade-offs between ensuring at least the enrolment of individual farms (relatively high p) and the payment level necessary to incentivize the coordination. This should then be compared in term of policy objectives and environmental process that determine the effectiveness of the environmental efforts. In other terms, if what only matters is coordinated effort, it would be cheaper to set $p=B=0$.

Having set T in such a way that the core is non-empty, the relevant question is how thee three farms share the grand-coalition worth. Different social preferences affect the likely distribution of the benefits, and this can be captured by comparing the worth allocation resulting from different CGT solutions.

3.4.2 Numerical example

As a numerical example I use land rental prices as a proxy for farming productivity. Data are taken from the database on rental price compiled by the Istituto Nazionale di Economia Agraria (INEA)[11]. Data refers to rental prices of 2013 in E-R. More specifically I use:

- Farm 1: min and max value for irrigated arable crop in the province of Bologna ($y_{1,L}=500$ €/ha; $y_{1,H}=1000$ €/ha);
- Farm 2: min and max value for biogas crop in the province of Bologna ($y_{2,L}=1000$ €/ha; $y_{2,H}=1200$ €/ha);
- Farm 3: min and max value for horticulture in the province of Ferrara ($y_{3,L}=800$ €/ha; $y_{3,H}=1300$ €/ha).

Having this range of parameters, no farms enrol in the policy program as long as $p<500$; there is only farm 1 enrolling if $500<p<800$, farm 1 and 3 if $800<p<1000$ and all the three farms if $p>1000$.

[11] http://web.inea.it:8080/mercato-fondiario/banca-dati

3.4.3 Results

Table 3.2 shows the minimum level of AB (*B*) to activate each two-farm coalition, for each level of payment (*p*). Clearly, the higher the payment, the higher the level of *B*.

Coalitions	*p=405*	*p=505*	*p=805*	*p=1005*
(1,2)	*2200*	*2205*	*2505*	*2710*
(1,3)	*2300*	*2305*	*2610*	*3010*
(2,3)	*2500*	*2500*	*2505*	*2710*

Table 3.2. Minimum level of AB required for each two-player coalitions to cooperate

As it was noted in the previous section, the level of T required to ensure that the core is non-empty and to ensure the convexity of the game is increasing more than proportionally in both *p* and *B*, reaching a maximum of respectively 1507 €/ha and 1676 €/ha. These levels represent respectively an increase by 50% and 67% with respect to the payment required for the three farms to contract land non-cooperatively if both type of incentives are faced at the same time (Figure 3.12).

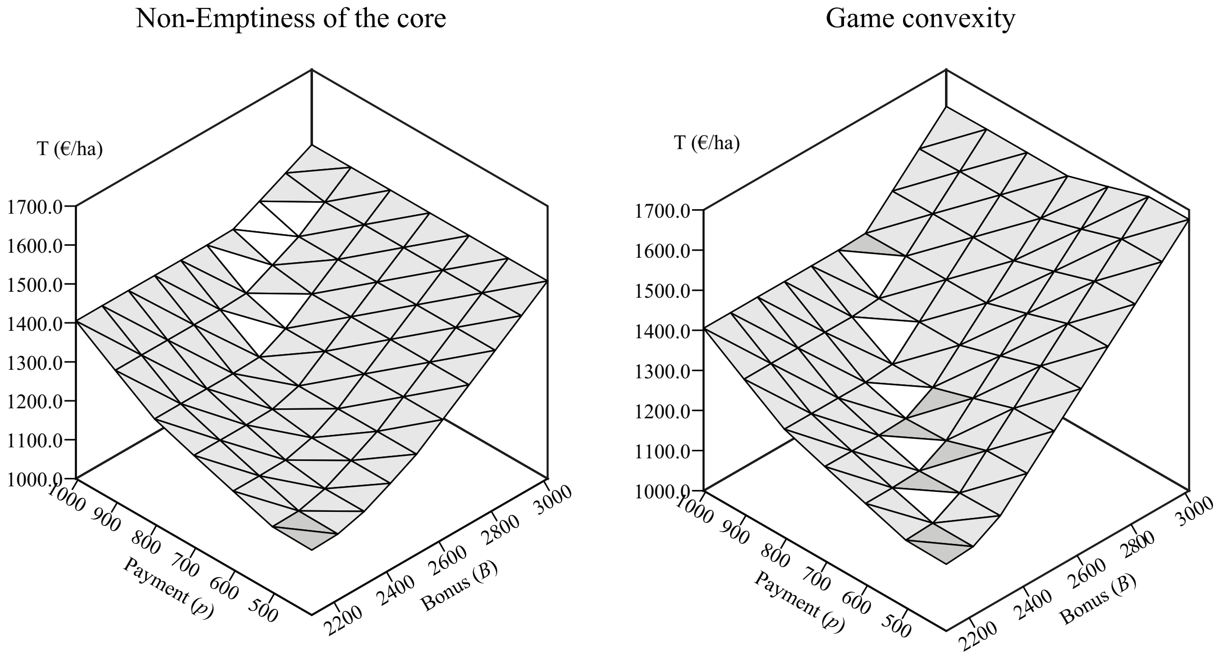


Figure 3.12. Minimum level of *T* to ensure non-emptiness of the core (left) and convexity of the game (right)

4 Modelling collective conditionality constraints in rural policies: the distributional effect

4.1 *The Shapley value*

In this section I analyse the effect of incentive levels and collective conditionality constraints on the distribution of the benefits of a common project. The analysis is applied to water resource development; more specifically I investigate the effects that incentives and MPR have on the SV of players pooling resource for the construction of a collective reservoir. The analysis attempts to ex-ante assess the distributional impact of policies similar to measure 125 of the 2007-2013 E-R RDP. The analysis is subdivided in two parts. In section 4.2 I analyse the issue in a more simplified and theoretical setting, where 3 farms decide on the reservoir size and on the distribution of the benefits. The simplification is needed to have a basic understanding on the logic of the problem. Next, in section 4.3, the same issue is framed in a cost allocation problem parameterized on data from the construction of an actual reservoir.

CGT has often been applied to water management (Dinar and Nigatu, 2013; Loehman et al., 1979; Madani and Dinar, 2012; Young et al., 1982). The SV is a unique solution that in the case of convex games surely satisfies the previous disequations, and is thus in the core (Shapley, 1971, 1952):

(4.1) $$u_i^{SV} = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{\left(n-|s|\right)!\left(|s|-1\right)!}{n!}\left[v\left(S\right)-v\left(S-\{i\}\right)\right]$$

where for $\forall i \in N$: $|s|$ is the number of members in the coalitions, and n is the total number of participants in the game. Equation (4.1) states that the worth attributed to the i^{th} player through the SV is given by its average marginal contribution to any possible grouping of the players. Shapley (1971) showed that such a value is surely in the core, it is its centre of gravity, in case of "convex games".

4.2 *The reservoir construction game - theoretical*

4.2.1 Theoretical analysis: effect of q-rule and n-rule

Assume a number of farms have to build a reservoir to make water available for irrigation. Further imagine that farms can pool together their resources to build the reservoir. The mathematical notation of such a game follows. Assume that the characteristic function is defined by the following maximization problem, namely each coalition must solve:

(4.2) $$\max\left[R-\left(1-\alpha P\right)k\left(Q_s\right)\right]$$

with $Q_s = \sum_{i \in s} Q_i$ and $R = \sum_{i \in s} f^i\left(Q_i\right)$ where R is the sum of the individual revenues of the members of coalition s; $k(Q_s)$ is the cost of the reservoir construction exhibiting economies of scale ($k'(Q_s) > 0$ and $k''(Q_s) < 0$). The coalition has to maximize the difference between the sum of the individual benefits generated by irrigation, and the costs of constructing a collective reservoir, which depend on the aggregate amount of water requested. P is a binary variable that indicates whether the coalition participates or not in the RDP, α is the share of the costs covered by the RDP. In case there is no public support ($\alpha=0$), the first order conditions lead to: $f^i_{q_i} = f^j_{q_j} = k_{q_s}$ (if there were three farmers it would be: $f^i_{q_i} = f^j_{q_j} = f^z_z = k_{q_s}$).

The introduction of a q-rule (as MPR) provides the financial support conditional on the minimum size of the reservoir capacity:

$$P = \begin{cases} 0 \text{ if } Q_s < q^t \\ 1 \text{ if } Q_s \geq q^t \end{cases} \tag{4.3}$$

where q^t is the q-rule threshold above which the coalition can be granted the financial support of the RDP. Equation (4.2) entails a binary variable and cannot be solved analytically. There are two choice variables: the water quantity demanded by the farms, and whether or not it is profitable to participate in the RDP given the threshold and the share of the costs covered by the RDP. Assume for the moment $q^t=0$, i.e. there is no q-rule. In the case of a coalition of players i and j, the first order conditions for the financial support case are: $f^i_{Q_i} = f^j_{Q_j} = \alpha k_{Q_s}$. Now, call $Q_s^{*,NP}$ *and* Π_s^{NP}, $Q_s^{*,P}$ *and* Π_s^{P}, $Q_s^{*,P,t}$ *and* $\Pi_s^{P,t}$ respectively the optimal amount of water and profits with *i)* no policy participation, *ii)* in the case of $q^t=0$, and *iii)* in the case of $q^t>0$. Given the assumptions on the shapes of the functions, I have that $Q_s^{*,P} > Q_s^{*,NP}$ *and* $\Pi_s^{P}, > \Pi_s^{NP}$. As long as $Q_s^{*,P} \geq q^t$ the problem is trivial, the coalition participates in the RDP, and $Q_s^{*,P} = Q_s^{*,P,t}$. However, if $Q_s^{*,P} < q^t$ then I have $Q_s^{*,P,t} = q^t$; hence in such a case the eligibility constraint imposes a cost on the coalition since the minimum amount of water imposed is larger than the optimal one. Moreover, in this condition coalition s participates in the RDP only if $\Pi_s^P > \Pi_s^{NP}$ for any level of q^t; there is thus a threshold $q_s^{t,NP}$ above which the coalitions no longer enrol in the policy. Accordingly, the characteristic function of the game when a q-rule applies is:

$$v(s) = \begin{cases} \Pi_s^P \text{ if } Q_s^{*P} \geq q^t \\ \Pi_s^{P,t} \text{ if } Q_s^{*P} < q^t \text{and } \Pi_s^{P,t} \geq \Pi_s^{NP} \\ \Pi_s^{NP} \text{ if } Q_s^{*P} < q^t \text{and } \Pi_s^{P,t} < \Pi_s^{NP} \end{cases}$$

The theoretical analysis previously described is depicted graphically in Figure 4.1.

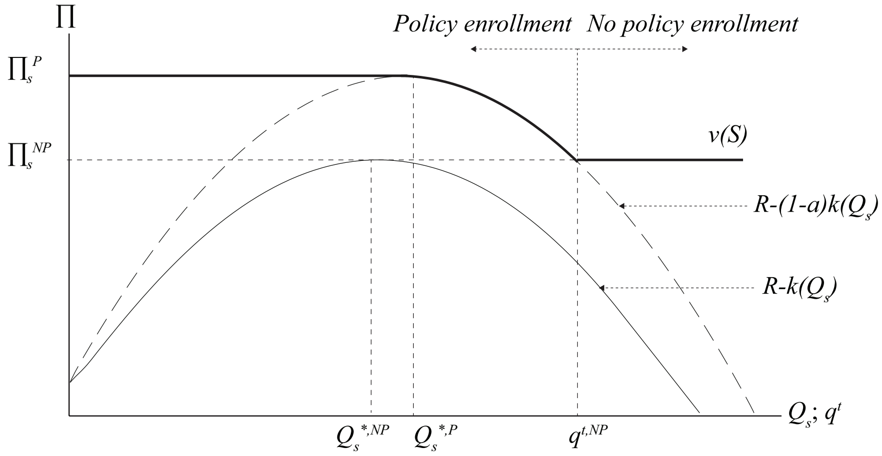


Figure 4.1. Graphical analysis of the construction of the characteristic function

The introduction of an n-rule, by setting a threshold on the number of participants (n^t), into the game adds another constraint that changes equation (4.3) into:

$$(4.4) \qquad P = \begin{cases} 0 \text{ if } Q_s < q^t \text{or} |s| < n^t \\ 1 \text{ if } Q_s \geq q^t \text{and} |s| \geq n^t \end{cases}$$

The characteristic function thus becomes:

$$v(s) = \begin{cases} \Pi_s^P \text{ if } Q_s^{*,P} \geq q^t \text{and } |s| \geq n^t \\ \Pi_s^{P,t} \text{ if } Q_s^{*,P} < q^t \text{ and } \Pi_s^P \geq \Pi_s^{NP} \text{and } |s| \geq n^t \\ \Pi_s^{NP} \text{ if } Q_s^{*,P} < q^t \text{ and } \Pi_s^P < \Pi_s^{NP} \text{and } |s| \geq n^t \\ \Pi_s^{NP} \text{ if} |s| < n^t \end{cases}$$

So far I have shown how a threshold affects the characteristic function of a single decisional unit; in Figure 4.2, however, I depict how the changes in the threshold affect the structure of the cooperative game when two players (*A* and *B*) can work together. Assume that the two players have different revenue function shapes with $Q_A^{*,P} < Q_B^{*,P}$. In addition, recall that given the shape of the cost function I have $Q_A^{*,P} < Q_B^{*,P} < Q_{(A,B)}^{*,P}$. As long as $q^t \leq Q_A^{*,P}$, $Q_B^{*,P}$ the gains from cooperation (the vertical distance between curve *v(A)+v(B)* and curve *v(A,B)*) are simply given by the economies of scale due to the cost function. Further increases in the threshold add to the economies of scale the fact that for singleton coalitions it is relatively more difficult to access the financial support, whereas it is still feasible for the coalition. Cooperation becomes more and more attractive because the threshold imposes costs on the smaller coalition. This continues as long as $q_A^{t,NP}$, $q_B^{t,NP} \leq q^t \leq q_{(A,B)}^{t,NP}$, namely when the gains from cooperation are at the their highest level.

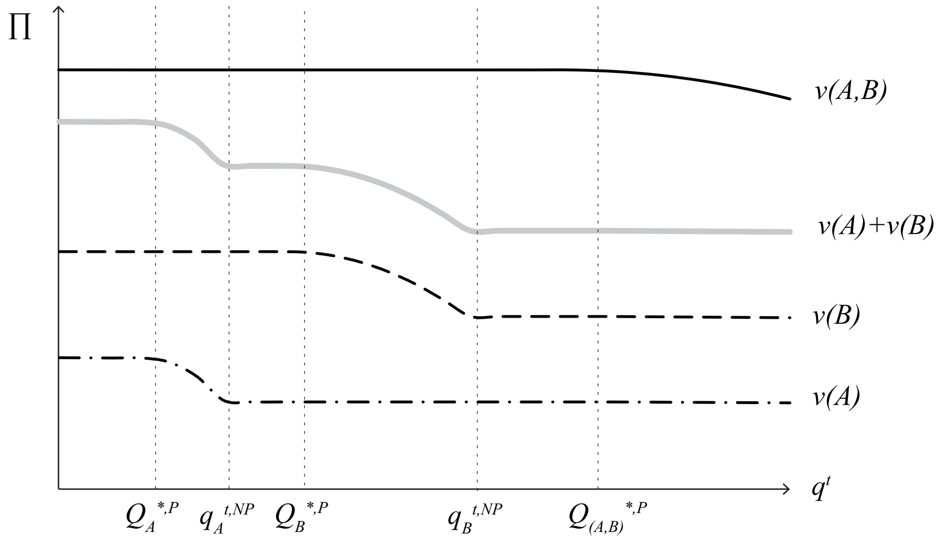


Figure 4.2. Gains from cooperation as a function of the threshold for two players

As is also clear from Figure 4.2, if farms are heterogeneous, MPR affects the game asymmetrically: the increases in the gains from cooperation due to the MRP are first due to the decrease in the profits of player *A* (from $Q_A^{*,P}$ on), and then due to the decrease in the profits of player *B* (from $Q_B^{*,P}$ on). This asymmetry influences the relative bargaining power within the grand-coalition. Consider the two q-rule levels $q^I < q^{II} < Q_N^{*P}$, which do not affect the worth of the grand-coalition. Imagine a coalition *{A,C}* for which $v(A,C)= \Pi_s^P|q^I$ and $v(A,C)= \Pi_s^{N,P}|q^{II}$. The increase in the threshold reduces the potential worth of *{A,C}*, and increases the relative gains from full cooperation, hence increasing the room for bargaining given that the core is bigger. Moreover, the share of the grand-coalition's worth for player *B* is thus greater now, since coalition *{A,C}* has now a lower opportunity cost of fully cooperating with player *{B}* (or, in other terms, cooperation for them becomes relatively more attractive). The SV accounts for these changes since it reflects the relative bargaining power of the coalitions, and the marginal contributions that each member brings to a given coalition. Figure 4.3 provides an illustrative example of the logic just described for a three-player game, which can be represented by an equilateral triangle. The distances from any point within the triangle to the three sides represent the share of the grand-coalition worth assigned to the player at that position. The light grey areas represent individual rationality constraints, the dark grey areas represent the group rationality constraints and the blank area is the core. From left to right we can observe how an increase in the threshold might increase the size of the core. The reduction in the value of the coalition *{A,C}* due to the threshold increase is exploited by player *B* that can now legitimately demand a higher share of the grand-coalition's worth. The SV – the centre of gravity of the core – (represented by a black dot) moves upward.[12]

[12] The numerical example from which the figure is drawn is the following (in percentage terms of the grand-coalition's worth): on the left I have *v(A)=10*; *v(B)=10*; *v(C)=10*; v*(A, B)=40*; *v(A, C)=50*; *v(B, C)=60*; the right part is only differentiated by setting *v(A, C)=25*.

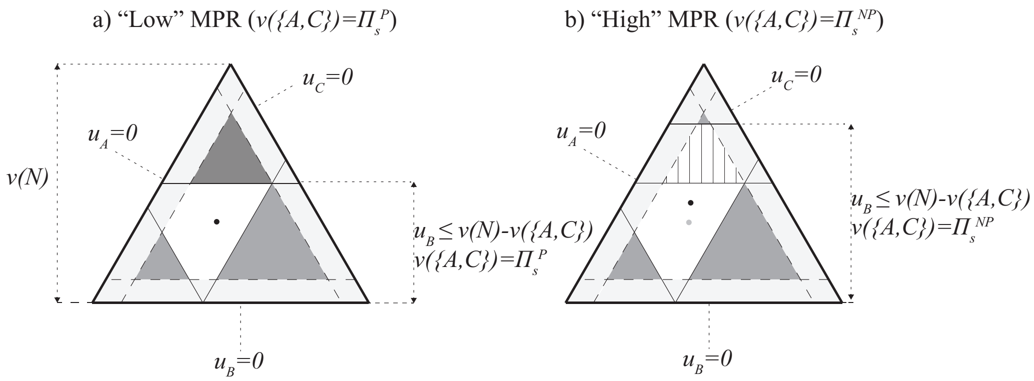


Figure 4.3. Illustrative example of how q-rules affect the core and the SV of a game

The effect of the q-rule rule clearly depends on the composition of the farms playing the game and on their characteristics. The degree of heterogeneity and the factors affecting water productivity may differ from area to area. In the case study area used in the numerical example below, the key features are the crop mix and size. Crop mixes with higher shares of fruit (especially kiwi) have a much higher productivity of water and a more rigid demand curve; farms with a larger share of annual crops show the opposite. Larger farms tend to have a larger share of annual crops. On the other hand, an n-rule, by counting only the heads, affects the game independently of the farm characteristics. As a result of the above analysis, the overall effect of the introduction of a MPR on the game and on the worth distribution is an empirical question. In the next section I provide a numerical example with secondary data from the E-R region.

4.2.2 Numerical application and results

4.2.2.1 Data

Here I apply the previous analysis to a numerical example for illustrative purposes, parameterizing the model as much as possible on actual data while maintaining the tractability and intelligibility of the game. However, there is a clear trade-off between tractability and i) the ability of the model to represent the heterogeneity of the composition of the farmers in the group, and ii) the degree of discrepancy with respect to the actual number of users in each reservoir, which are in a range of 20-50 in the case study area (CBRO, 2015). The example is based on secondary data taken from the E-R region, from an area where irrigation water is managed by the CBRO, a local Water User Association.

Assume there are *3* farms (*A*, *B*, *C*) characterised by different levels of water productivity. As a numerical example, I take $f(Q_s)$ from the quadratic interpolation of the gross margin resulting from a sensitivity analysis on water availability from a model by Viaggi et al. (2010). The model defines a quadratic revenue function on the amount of water and is parameterized on land availability (*l*):

(4.5) $$\Pi_s = \sum_{i \in s} l_i \left(\eta Q_i^2 + \beta Q_i + \gamma \right)$$

The three farms represent three different farm typologies, generated by a cluster analysis, where the discriminants are farm size and share of land allocated to crops (Viaggi et al., 2010). The selected typologies are cluster 2 (farm *A*), cluster 3 (farm *B*), and cluster 4 (farm *C*). All three of the farms have a relatively high share of crops allocated to permanent crops (highly dependent on water availability) and they represent the most frequent farm typologies. The farm specific parameters are found in Table 4.1. It can be observed that three farms are relatively heterogeneous in terms of both land availability, and water productivity. Farm *A* is the smallest and the one with the steepest revenue function.

	Farm *A*	Farm *B*	Farm *C*
η	*-0.0002*	*-0.0005*	*-0.0006*
β	*1.2017*	*1.1498*	*1.1803*
γ	*680.22*	*747.05*	*817.76*
l	*4.19 ha*	*13.22 ha*	*33.85 ha*

Table 4.1. Farm specific parameters

The construction costs of the reservoir are given by the annualization (at the rate of $\lambda=0.05$) of the investment costs derived from the following function: $140(Q_S)^{0.641}$. The cost function is formulated in collaboration with officials of the CBRO, and represents the interpolation of the costs assessment of a number of planned reservoirs with different capacity levels. Moreover, running costs are introduced to account for electricity and management. I assume that running costs are dependent on the coalition size and account for economies of scale in management and more likely water scarcity for the smaller reservoirs. According to CBRO officials, these are key factors to be considered when decisions on building reservoirs are made. These are then $c=0.45$ if $|s|=1$, $c=0.30$ if $|s|=2$, and $c=0.15$ if $|s|=3$. I do not address the problem of the connection costs among the farms and the reservoir as a three-player game does not allow to properly representing the complexity of such an issue (spatial elements, congestion costs). However, officials of the CBRO report that these costs can be higher than 50% of total costs for existing reservoirs. The drawback is thus that the model is most likely to overestimate reservoir capacity. The final cost function is then $k\left(Q_s\right)=\lambda 140\left(Q_s\right)^{0.641}+c\left(Q_s\right)$. Table 4.2 lists profits and reservoir capacity in the absence of policy and in case of $k(Q_s)=0$.

	$k(Q_s)=0$		$\alpha=0$	
0	*Qs*	Π_s	*Qs*	Π_s (€)
{A}	7536	5578	5637	3610
{B}	9403	12893	7067	10622
{C}	21191	34918	17542	30996
{AB}			16091	16585
{AC}			28243	38328
{BC}			30173	45620
{ABC}			45727	57438

Table 4.2. Results in the absence of policy and no costs

I explore the characteristic function and the SV for different levels of q-rules and n-rules ($n^t=1$, $n^t=2$, $n^t=3$) in case of $\alpha=70\%$. Once again, the tractability of the results imposes a simplification and scaling down of the rules applied for the example described here ($n^t=20$, and $q^t=50000$ m^3 are the actual rules). While the share of the public financial contribution is the nominal share indicated by the policy document, some costs are not actually covered, and for this reason I run a sensitivity analysis on α ($\alpha=30\%$ and $\alpha=50\%$,); the results are not qualitatively different and are hence provided only in the Appendix (section 7.6, Figure 7.1).

Next I describe the results of the simulations. I first describe how the characteristic function varies with changes in the threshold. I then analyse the effect of the q-rule and the n-rule on the SV. Finally, I restrict the attention to the specific gains from enrolment in the policy.

4.2.2.2 Results: characteristic function for different levels of the q-rule

Figure 4.4 shows the average percentage increase in the payoff of the grand-coalition with respect to the other possible arrangements. The q-rule imposes costs when the level is above the optimal amount of water for the given coalition. The figure also reports the level of q-rule above which each coalition withdraws from the policy. As it is clear from the figure, the size of the farms plays a key role given that the q-rule is in absolute values. An increase in the q-rule level rapidly forces *{A}* and *{B}* as singletons to withdraw from the policy, and does likewise to the bigger coalitions and *{C}*. Increasing the threshold increments the attractiveness of the full cooperative arrangement. It should be recalled that the gains from cooperation in our game come from the economies of scale due to the cost function and from the participation in the policy. Above $q_t=35000$ any singleton coalition does not access the RDP (since it is not profitable), and the policy benefits are only ensured by joining the grand-coalition. This continues up to $q_t=45000$, after which the q-rule also imposes costs on the grand-coalition's worth and thus restricts the gains from cooperation. Above $q^t=75000$, even the grand-coalition withdraws from the policy, and the only gains from cooperation are due to the economies of scale of the original game, which sets a floor for the characteristic function of the game, and which is no longer affected by the policy (hence further values are not reported). The gains from any possible arrangements are reported in the appendix (section 7.6, Figure 7.2).

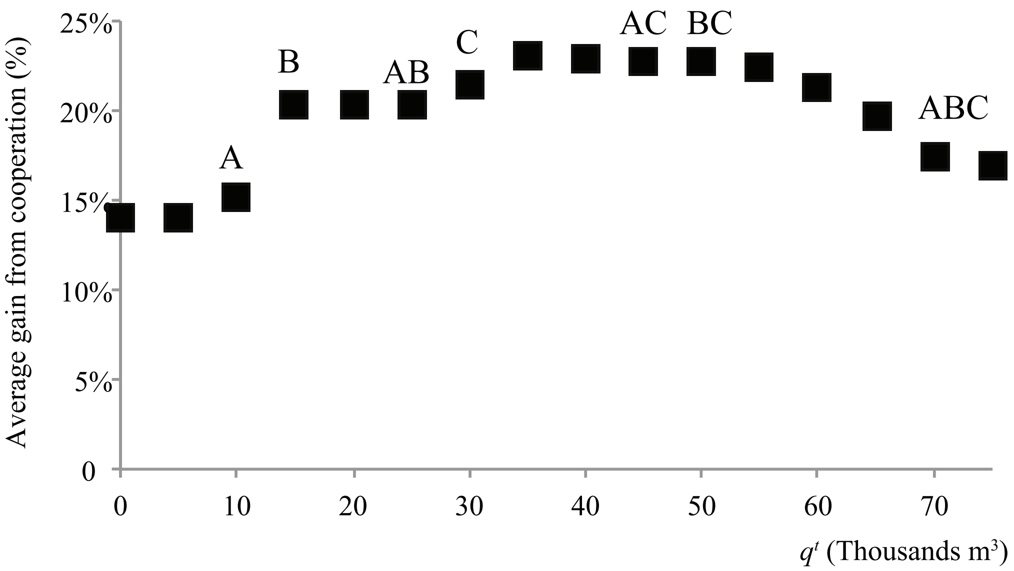


Figure 4.4. Gains from cooperation (profits - %) for different levels of RDP financial support. The letters above the points indicate the threshold above which the given coalition withdraws from the policy

4.2.2.3 Results: Shapley value and q-rule

Figure 4.5 presents the SV in terms of share of the grand-coalition's total worth for the three farms and for different levels of the q-rule (absolute values are reported in the Appendix, section 7.6, Figure 7.3). All the relative changes in the SV across the different policy schemes and threshold levels are due to relative changes in the opportunity costs of the arrangements other (smaller) than the grand-coalition. Consider that $Q_N^{*,P} \geq q^t$ holds up to q^t*=45000*, so in this range the threshold does not affect the grand-coalition's worth, and any change in the SV is only due to the costs imposed by the q-rule on the smaller arrangements. For higher levels of q^t the whole worth is affected and results are not presented.

First, not surprisingly, farm *C* (i.e. the biggest one) gains the highest share, followed by farm *B* and finally farm *A*. The q-rule does not affect this ranking. This is due to, and reflects, the high heterogeneity in farm composition. Second, both farms *A* and *B* decrease their SV up to q_t*=30000*, whereas the opposite occurs for farm *C*. The q-rule affects farms *A* and *B* more (compare with Figure 4.4) by forcing both of them as singletons and as a coalition to withdraw from the policy for lower values of the q-rule. Their opportunity costs of not joining the grand-coalition are much lower and decrease rapidly so that farm *C* can legitimately claim a progressively larger share of the grand-coalition's worth. Above q^t*=30000*, singletons *{A}* and *{B}* and coalition *{A,B}* are not affected by increases to the q-rule. Within the same range of q^t levels, *{C}* withdraws from the policy, and its only chance to obtain financial support is now by joining with the other farms. Its opportunity costs are thus decreased, as is its share of the grand coalition's worth. For values above q^t*=50000*, relative changes are simply due to the reduction in the grand-coalition's worth. This makes this farm the most powerful since it is the one with highest opportunity cost of joining the grand-coalition.

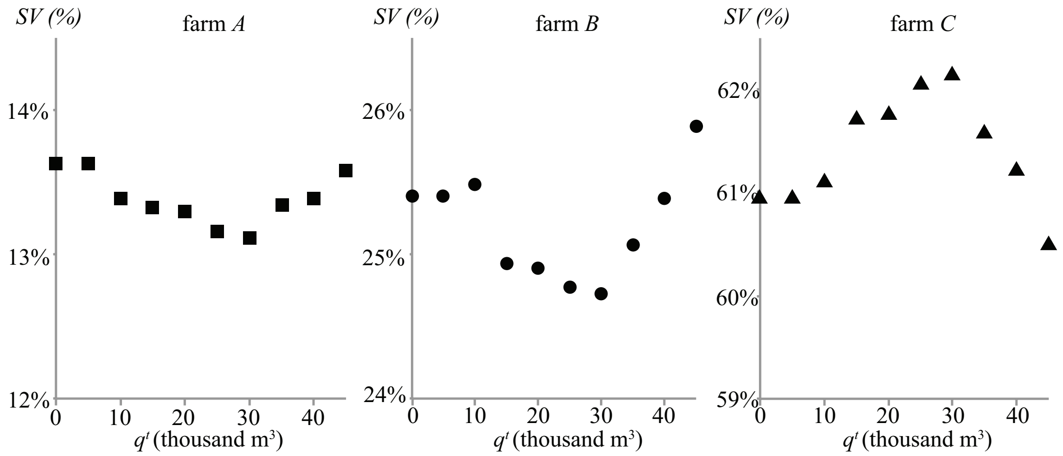


Figure 4.5. SV (share of the grand-coalition's worth) for the three farms and q-rule levels.

Values are rather stable over the changes in q^t, since the costs due to the threshold are modest. However, to better appreciate the effect of the q-rule I depict in Figure 4.6 how the SV changes in percentage terms with respect to $q^t=0$. Changes in the SV due to the increase in the q^t range between +2% for farm *C*, and -4% for farm *A*.

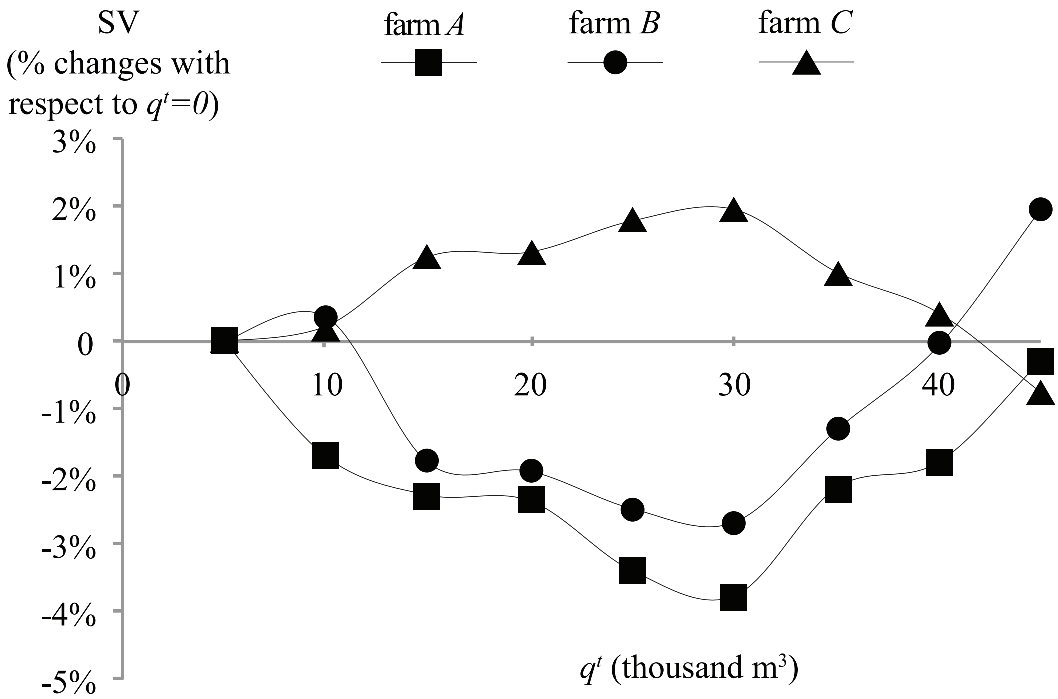


Figure 4.6. Percentage changes in the SV for different levels of q^t with respect to $q^t=0$

4.2.2.4 Results: Shapley value and n-rule

Figure 4.7 depicts the SV for the three farms when the support, in addition to q^t, is granted conditionally on the number of players participating in the project. When this condition is $n^t=1$ results are equivalent to the previous sections; they are nonetheless reported here to be compared with a situation where the financial support is granted if $n^t=2$ *and* $n^t=3$. Obviously, when $n^t=3$, the size-rule becomes irrelevant for the range of values here reported. The results show that the n-rule has a different and neater effect on the SV. First, the higher the n-rule, the higher the SV of players *A* and *B*, and the lower the share of player *C*. Size matters relatively less, since the big players cannot have access to the greater advantage of cooperation granted by access to the RDP and need the cooperation of the smaller farms.

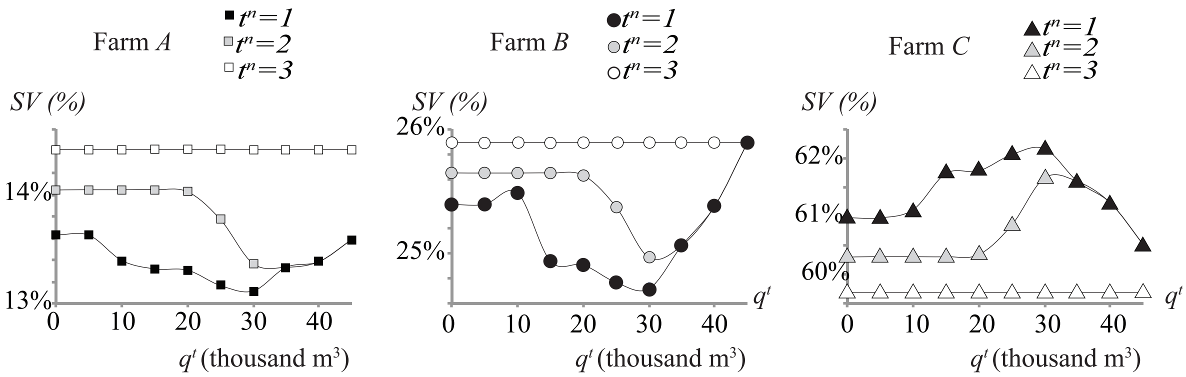


Figure 4.7. SV for the three farms, threshold levels and n-rule

Second, the n-rule has a greater effect than the q-rule. This is clearer from Figure 4.8 where I depict the percentage change in the SV in case $n^t=2$ and $n^t=3$ with respect to $n^t=1$, namely when there is no n-rule. The n-rule $n^t=3$ increases the SV of farm *A* up to almost 10%, up to 5% for farm *B*, and up to -4% for farm C.

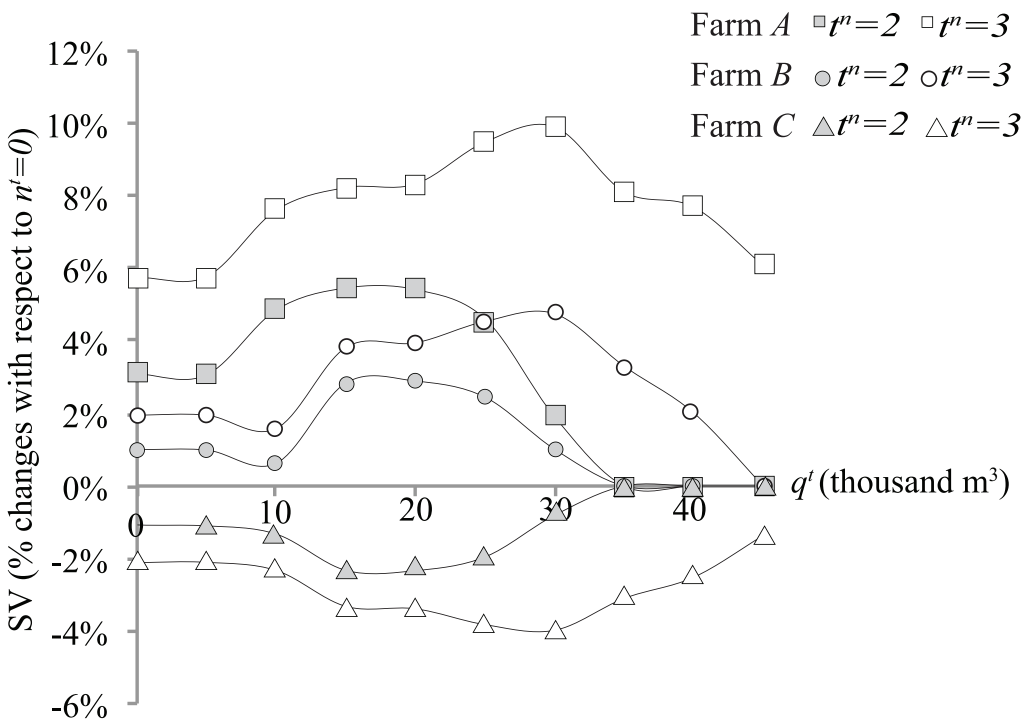


Figure 4.8. Percentage changes in the SV for different levels of q^t with respect to n^t=1

4.2.2.5 Results: Gains from the policy

So far I have shown the analysis of the entire "economy" of the three-player game. I now restrict the attention to the "policy" game, namely the gains from enrolling in the policy, taking for granted the game in the absence of the policy. I thus distinguish between the SV in the absence of the policy, $u_i^{sh,NP}$ and the SV with the policy, the one previously computed, $u_i^{sh,\,P}$.

Figure 4.9 graphically depicts $(u_i^{sh,\,P} - u_i^{sh,NP}) / u_i^{sh,\,NP}$, namely the percentage increase in the SV when the policy is present with respect to a counterworld where the policy is not provided, for the q-rule level. This makes possible to give a more accurate picture of the effects of the policy on the game. Farm *A* is the one that is the most attracted by participation in the policy since it has the steepest water revenue functions, and thus is the one that benefits relatively more from a decrease in the water costs. More similar are farms *B* and *C*. Farm *A*'s share is the most affected by the q-rule: the gains from the policy range from a 15% increase at $q^t=0$, down to an 11% when $q^t=30000$, and up again to a maximum of 21% when $q^t=50000$. Farms *B* and *C* are less affected by the q-rule: gains are in the range of 6% and 11% for farm *B*, and between 6% and 9% for farm *C*, within a range of values that do not affect the grand-coalition worth.

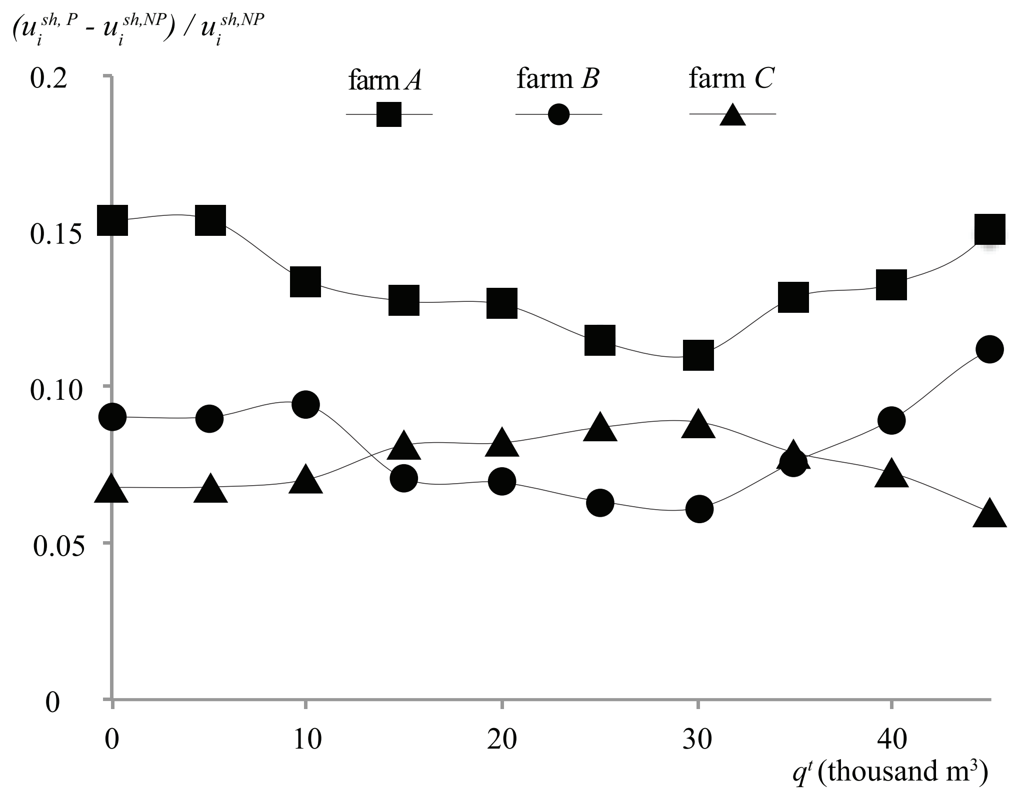


Figure 4.9. Increase in the SV from a non-policy scenario to a policy scenario for different levels of the q-rule

4.3 Reservoir construction – empirical

4.3.1 Model

Here I compute the SV of an actual reservoir under different level of MPR. Farmers are located in a network that conveys information of both farms location and the technology used for the construction of the reservoir (pipe network). The objective is the assessment of the effect of the MPR on the bargaining power of the farmers in two different social environments. In the first case the possibility of connecting to the reservoir is not affected by the location in the network, e.i. farms do not block the passage of pipes. In the second case, a given coalition can be prevented by accessing to the water in case all the coalition members are not all the nodes necessary to reach the water.

Assume there are a number of farms for which the availability of irrigation water is ensured by reservoirs. Assume that either a single collective reservoir or individual reservoirs can be built. Further imagine that if the MPR is met, the collective reservoir is subsidized by the regional administration. Here I assume that the collective reservoir can be built only in case the MPR is met. The assumption reflects observation on the case study area, where only in case the MPR is met, collective reservoirs are actually planned and built. This is due to the role of the CBRO, that provides skills and absorbs the transaction costs, and that can be rewarded only in case of the financial support. That implies that the sum of transaction and coordination costs could erode the benefits from cooperation.

4.3.1.1 Modelling costs

Assume the amount of water demanded is fixed. Assume the cost for the construction of an individual reservoir is given by: $c_i=C(q_i)$.

The collective reservoir is composed by two elements: the reservoir itself and the pipe network that delivers water to the connected farms (coalition). The cost for the construction of the reservoir are $c_S=C(q_S)$ where q_S is the total amount of water requested by the farms that are considered.

The pipe connections are modelled as a network tree (N,G). The nodes $N=\{1, \ldots, n\}$ of the network are both the farms ($F=\{1\ldots, n\text{-}1\}$) and the reservoir $\{n\}$. Call "*r*", for simplicity, the n^{th} node, the one representing the reservoir. G is a nxn matrix representing the weighted directed relations between each node (water flows in one directions, farms are spatially located in a watershed) so that $g_{ji} \geq 0$ and $g_{ij} \neq g_{ji}$ $\forall i \neq j$ and $g_{ii}=0$. The cost of the network depends on both the length of the pipes (links) and on the amount of water that has to pass by the pipes (bigger amount of water requires wider pipes). While distance is easily computed, the amount of water requires to determine who are the nodes that need to use a given link. To do so, I first find the path to the reservoir for each node, and then I observe to which path a link belongs. Denote P_{ri} the subset of nodes representing the shortest path from r to each farm *i*.[13] Call, for each farm, D_i the subset of farms for which *i* belongs to the path, namely: $D_i = \left\{ j : i \in P_{rj} \right\}$. For instance in the network in Figure 4.10 we have $D_a=\{a\}$, $D_b=\{b\}$, $D_c=\{a,b,c\}$.

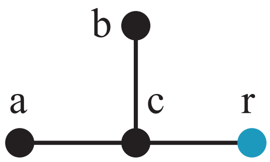


Figure 4.10. Example of network, where *a*,*b*,*c* represent farms, and *r* represents the reservoir

Observe that for instance by link *rc* has to pass the amount of water requested by *a*, *b* and *c*. The amount of water passing by each link (w_{ij}) is thus given by: $w_{ij} = \sum_{j \in D_j} q_j$, namely the amount of water of the farms whose paths pass through link *ij*. The cost for each link is then a function of the weights (the length of the link) and of the amount of water that has to pass: $k_{ij} = f\left(g_{ij}, w_{ij}\right)$. The total cost of the network is then given by: $\sum_{j,i} k_{ij}$.

The final cost of the collective reservoir is then given by:

$$TC = C\left(\sum_i q_i\right) + \sum_{i,j} k_{ij}$$

[13] It is the shortest path since in a tree there is only one path connecting two nodes.

4.3.1.2 The characteristic function in two scenarios

Given this general model I assess how the characteristic function is affected by social environment characterized by different degrees of attitude toward collaboration across farmers. I thus formulate two scenarios and two characteristic functions.

The first scenario is the collaborative scenario (CO) where, even though a farm does not belong to a coalition, it lets the farms in the coalition to have access to the reservoir. So for instance in Figure 4.10, a coalition formed by farms *a*, *b* still has access to the reservoir even though farm *c* is not a member of the coalition. In such a case the network does not affect the characteristic function (but distance between farms and the reservoir still matters).[14] Moreover imagine that financial support is granted only in case the amount of water of the coalition is greater than an exogenously given threshold q^t. Then the characteristic function is given by:

$$v^{CO}(S) = \begin{cases} \sum_{i \in S} C(q_i) & \text{if} \sum_{i \in S} q_i < q^t \\ \min\left\{ \sum_{i \in S} C(q_f);\ \ C\sum_{i \in S}(q_i) + \sum_i \sum_j k_{ij} \right\} & \text{otherwise} \end{cases}$$

$$\text{with } w_{ij} = \sum_{j \in D_{j \in S}} q_j$$

Call u_i^t the solution, the cost allocated to each player according to the SV, to this game for any level of q^t.

Imagine now a less collaborative environment where, in the previous example, farm *c*, as an exogenously given behaviour, does not enable the passage of the pipes. The only choice of coalition *{a,b}*is to build individual reservoirs. So the characteristic function:

$$v^{CO}(S) = \begin{cases} \sum_{i \in S} C(q_i) & \text{if } P_{rj} \not\subset S \text{ or} \sum_{i \in S} q_i < q^t \\ \min\left\{ \sum_{i \in S} C(q_i);\ \ C\sum_{i \in S}(q_f) + \sum_i \sum_j k_{ij} \right\} & \text{otherwise} \end{cases}$$

$$\text{with } w_{ij} = \sum_{j \in D_{j \in S}} q_j$$

Call m_i^t the solution, the cost allocated to each player according to the SV, to this game for any level of q^t.

A simple example clarifies the implication of the two social environments for the bargaining power, and a consequence for the SV, of the players according to their position in the network. Imagine a network as in Figure 4.10. Imagine each farm needs $q_i=3$ of water, and that the cost function is $\sqrt{\sum_{i \in S} q_i}$. In the collaborative environment we have $v(a,b)=6^{0.5}=2.45$, so that marginal contribution of *c* is $v(a,b,c)-v(a,b)= 3-2.45=0.55$. Costs for each player are hence: $u_i=1$.

[14] Note however that the action of farm c does not affect the payoffs of the coalition *{a,b,d }*.

In a non-collaborative environment *c* impedes that coalition *{bc}* collaborate in building the collective reservoir, so that $v(a,b)=v(a)+v(b)=1.7+1.7=3.5$. The marginal contribution of *c* to *(a,b)* is $v(a,b,c)$- $v(a,b)= 3$-$3.5=-0.5$. So in the second case the marginal contribution of *c* is so high that he should not be allocated any cost, but instead *(a,b)* should buy the entrance of *c* in the coalition. Clearly in the second case, in the non-collaborative environment the power of *c* is much higher, and as a consequence its share of cost is lower: $m_a=0.7; m_b= m_c=1.2$.

4.3.2 Empirical analysis and results

4.3.2.1 Data and empirical analysis

The model is applied to one of the reservoirs financed by the measure 125 in the province of Ravenna. 26 farms are connected to the reservoir, with heterogeneous water quotas. The reservoir capacity is about 50,000 m^3, subdivided in 74 quotas whose distribution is described in Table 4.3. Each quota is entitled of 676 m^3 of water. Note that the reservoir capacity is just at the threshold level necessary to make a project eligible for the measure 125.

Nr of Quota	*nr. of farms*
1	*6*
2	*9*
3	*2*
4	*7*
5	*0*
6	*0*
7	*0*
8	*2*

Table 4.3. Distribution of water quota per farm

Farms are connected to the reservoir by pressurized water pipes. A network is used both to represent the spatial location of the farms and to account for the technical choice that drove the design of the pipe network (Figure 4.11).

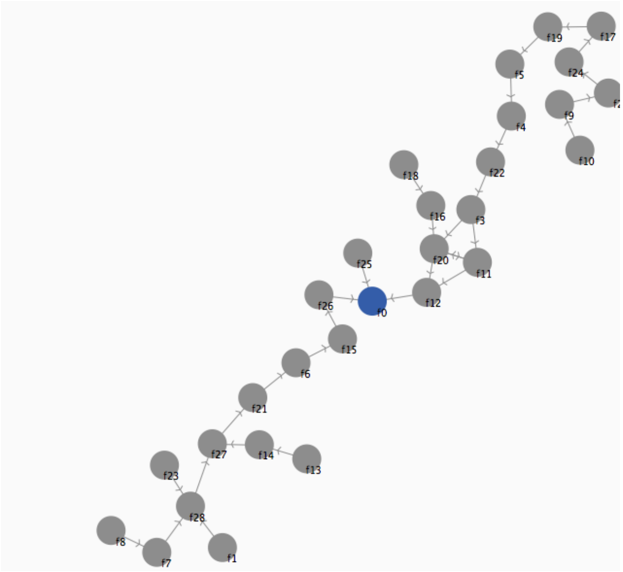


Figure 4.11. Pipe network of the case study. The adjacency matrix is available upon request

The cost function parameters related to the pipe network have been selected according to real costs of pipes and according to the actual pipes used in the example (Table 4.4).

w_{ij}	€/m
$0<w_{ji}\leq 4000$	7.6
$4000<w_{ji}\leq 13000$	16.2
$13000<w_{ji}\leq 25000$	52
$25000<w_{ji}$	68

Table 4.4. Cost of pipe network (€/m) according to the amount of water passing by the pipe.

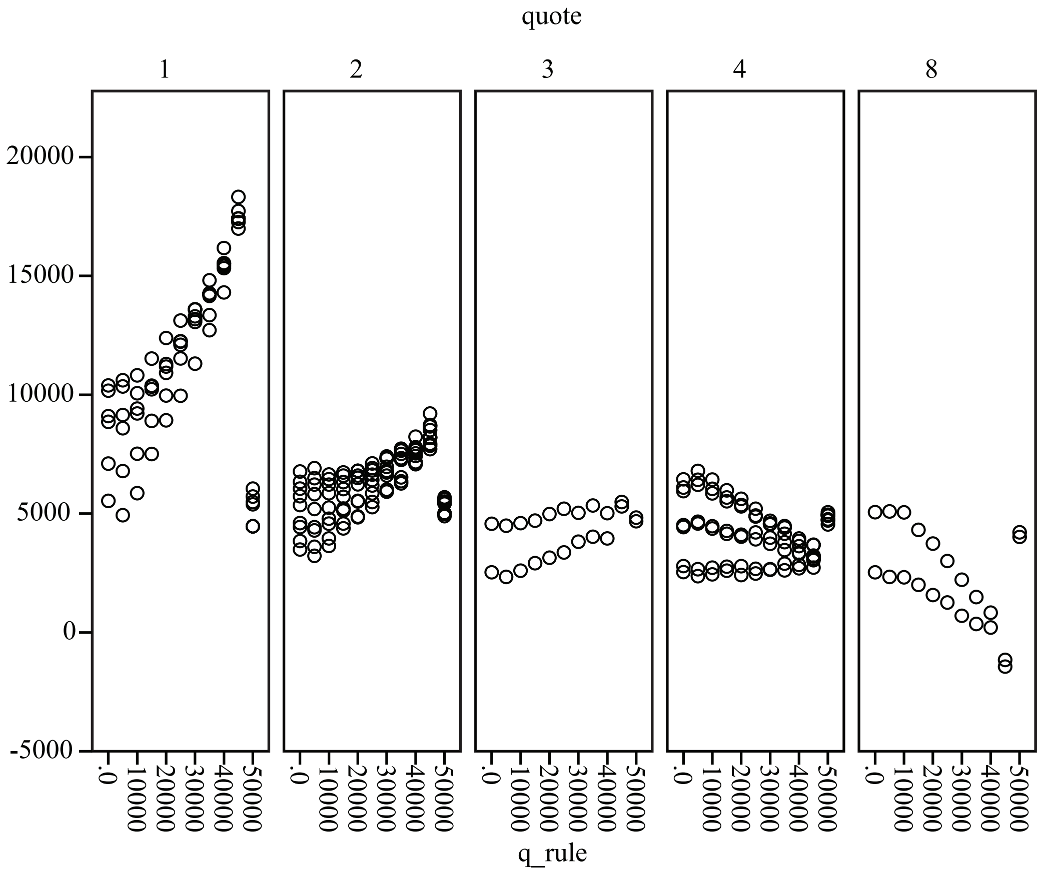
Other relevant parameters are the following. Land price is set at 40,000 €; Running costs are set at 0.4€/m^3 per individual reservoirs, and at 0.15 €/m^3 for the collective reservoir. The investment costs are derived from of the following function: $140(Q_s)^{0.641}$. which has been built in collaboration with officials of CBRO. The financial support is assumed to cover 50% of the costs; the policy actually covers 70%, but some of the costs are actually not covered so is ultimately less than the nominal 70%. I run a sensitivity analysis on q^t, using a range of values from q^t =0 to q^t =50,000 which is the actual threshold in measure 125. For the computation of the SV I use the sampling approach and the algorithm developed by Castro et al. (2009): I use a sample of 10000 orderings of the players.

4.3.2.2 Results

I first present the results of the model, then I carry out an OLS regression on the model results to have a better understanding of the forces at work. Farms are classified according to the amount of water requested (quotas).

Figure 4.12 shows on the y-axes u_i^t/q_i (€/quota, left) and m_i^t/q_i (€/quota, right) under different level of q-rule (x-axes); graphs are differentiated by farm classes. The graphs show that in the CO scenario the q-rule affects farm cost allocation according to the quota owned: farms with "small" amount of quotas (1-2) tend to be allocated higher costs as q^t increases; the opposite occurs for farms with bigger amounts (3-4-8). In the NC scenario the effect of the q-rule is much less evident. In the CO scenario the collective reservoir can be built only when the project is eligible for the regional financial support. As q^t increases, the probability that bigger players are the pivotal ones increases as well, and as a consequence their cost share diminishes. In the NC scenario, in addition to the q-rule, the collective reservoir can be built only when the player on the paths to the reservoir site are all members of the coalition. Thus owned quotas become relatively less important, or position in the network attributes higher power, so that the effect of the q-rule vanishes.

CO scenario (u_i^t/q_i)



NC scenario (m_i^t/q_i)

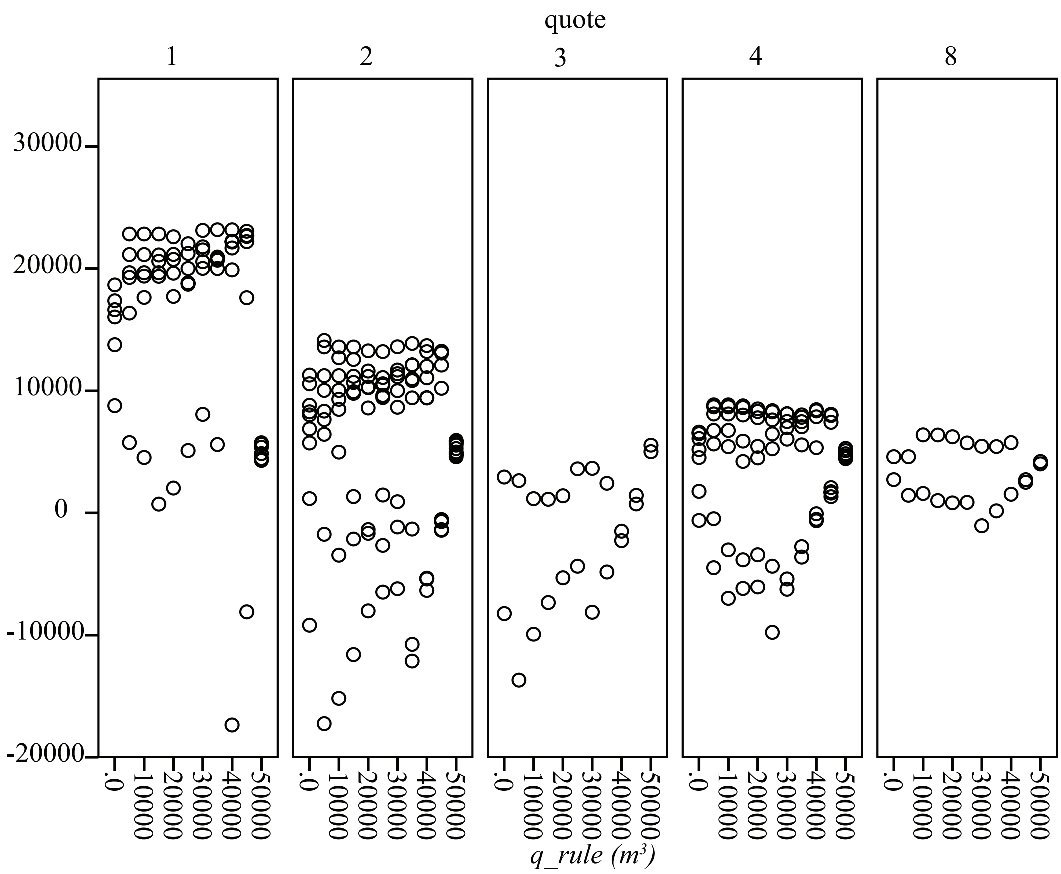


Figure 4.12. Allocation of costs per quota in the CO scenario (u_i^t/q_i, upper graph) and in the NC scenario (m_i^t/q_i, bottom graph) under different q-rule levels

To further analyse the differences between the scenarios, Figure 4.13 shows the average costs per farm classes in the CO and in the NC scenarios and Figure 4.14 shows the related coefficient of variation (CV). The pictures show that in case $q^t = 0$ (no MPR) the allocation of costs in the CO scenario is much less variable (CV=0.4) than in the NC scenario (CV=1.02). Moving to the right, by increasing q^t up *45000*, the CO scenario is more affected than the NC scenario by changes in policy: the CV of u_i^t/q_i varies between 0.7 and 0.4; the CV of m_i^t/q_i varies between 1.5 and 1.0. When $q^t=50000$ (which means that only the grand-coalition can have access to the subsidy of the regional administration) the CV of the CO scenario (0.10) is very similar to the one in the NC scenario (0.11). In such a case only the grand-coalition (when all the players cooperate) is eligible to the regional subsidy, and the pivotal player is always the last one in any given order. In other terms, the probability of being the pivotal player does not depend on any personal characteristic of the players (like water quotas, or network position) and as a consequence bargaining power and costs allocated become very similar across players. The position in the network is much less important in affecting the largest marginal contribution, namely when a player is the pivotal player in determining the access to the financial support. Further note that in this setting the q-rule at the unanimity level affects the cost distribution much more in a non-collaborative environment than in a collaborative environment.

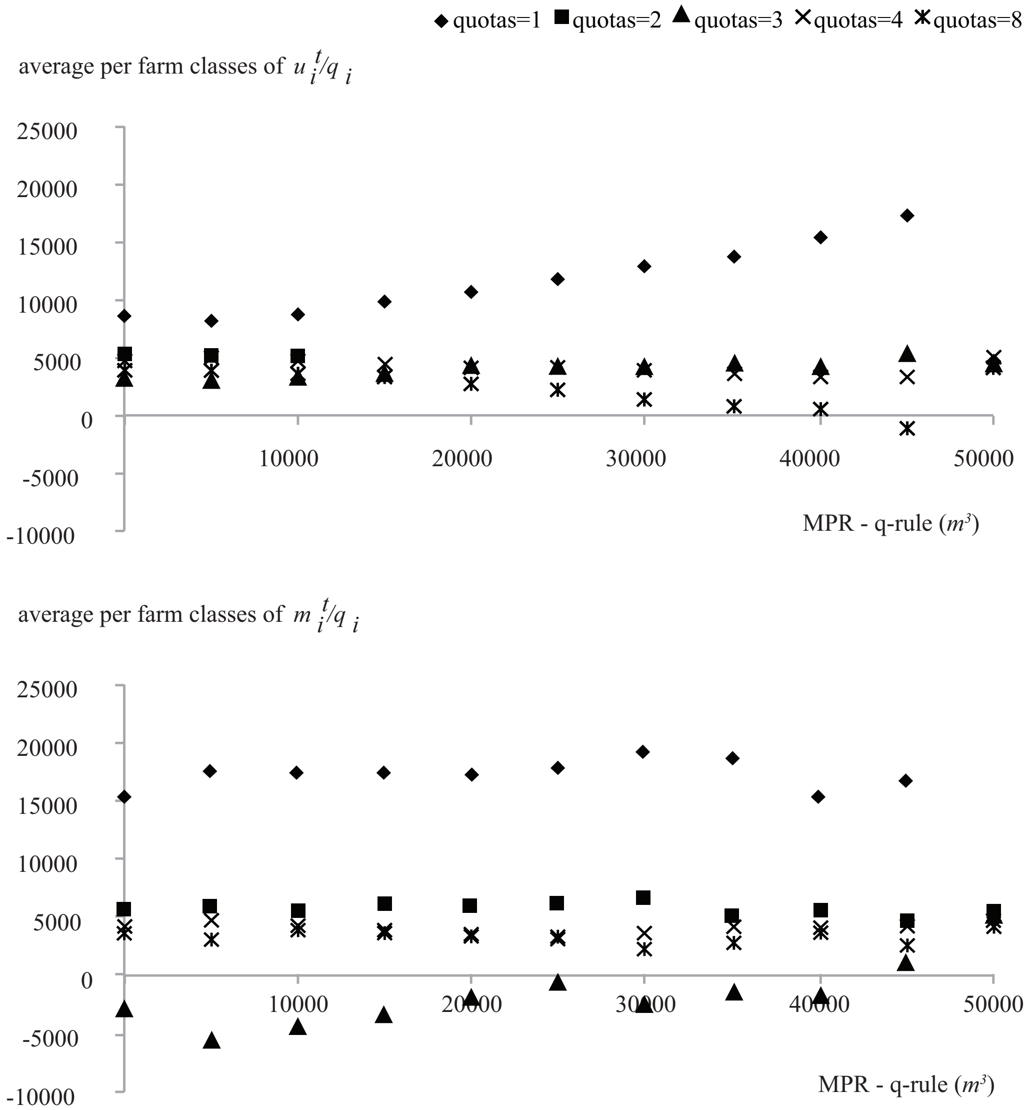


Figure 4.13. Average SV in the CO scenario (upper graph) and in the NC scenario (bottom graph) per classes of farms.

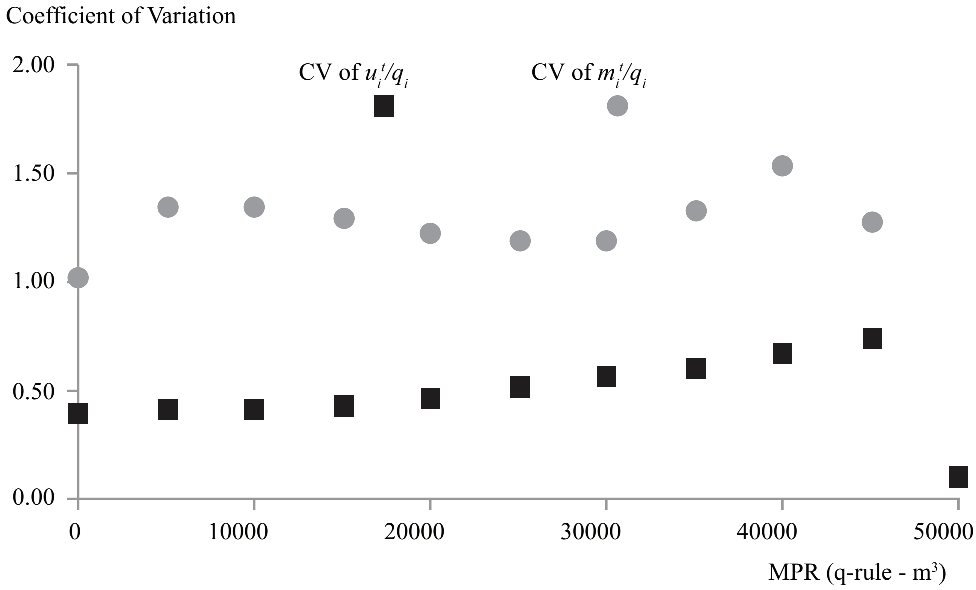


Figure 4.14. Coefficient of Variation (CV) of Average SV in the CO scenario (squares) and in the NC scenario (circles).

To disentangle the different elements that affect the individual cost allocation in the two scenarios I carry out an ex-post analysis of the model results by mean of OLS regressions. Clearly the regressions are not aimed at testing the validity of a model, but to gain understanding of the (simulated) model results, which is the outcome of a stochastic process. Two regression models are formulated with the same explanatory variables, and with two dependent variables, that is u_i^t and m_i^t. Results are respectively in Table 4.5 and Table 4.6. The explanatory variables are the following:

i) the amount of water requested by each farm (q_i);
ii) the distance of each farm from the reservoir (*distance*);
iii) the number of agents whose water passes though each farm (from section 4.3.1, $|D_i|$),
iv) the amount of water passing by each farm (from section 4.3.1, w_{ij});
v) the power of each player (*power*).

The assessment of the "power" of players in a cooperative game is one of the earliest application of the SV, which was used to assess the distribution of power within a committee (Shapley and Shubik, 1954). The idea is that a decision is approved only when the sum of the votes (say q_i) are higher than a given threshold (say q^t). Thus the characteristic function is $v(S)=0$ *if* $\sum_{i \in S} q_i < q^t$, $v(S)=1$ otherwise. The SV is then the relative frequency of when a player is the pivotal player. The committee game clearly resembles the policy game that I have modelled here (the regional subsidy is granted only in case the reservoir capacity is bigger than a predetermined threshold). The power thus also includes the relationship between owned quota and policy threshold. The inclusion of such an explanatory variable in the model is thus aimed at disentangling the effect of the power with respect to the policy with the other factors that affect the benefit distribution (economies of scale and network costs).

The ex-post analysis shows that q_i is clearly positive related to both u_i^t and m_i^t: the higher the quota, the higher the costs allocated to a farm; however the relative importance of q_i is reduced from the CO scenario (beta=1.1) to the NC scenario (beta=0.5). The $|D_i|$ coefficient changes sign when passing from CO (beta=0.323) to NC (beta=-0.541) which shows the effect of the position in the NC scenario. Finally, the power of the players is negatively related to u_i^t, (the higher the power, the lower the allocated cost), but becomes irrelevant in the NC scenario (significance=0.075). Thus the regressions further show how policy rules (q-rule) interact with farm characteristics (water needs), spatial relations, and social structure (collaborative vs non-collaborative scenarios) to determine the bargaining power of the players.

Explanatory variables	Unstandardized Coefficients		Standardized Coefficients	t	Sign.
	B	Errore std.	Beta		
(Constant)	*6079.191*	*1005.981*		*6.043*	*0*
q_i	*3566.437*	*316.49*	*1.113*	*11.269*	*0*
Distance (km)	*0.789*	*0.19*	*0.24*	*4.149*	*0*
$\lvert D_i \rvert$	*456.278*	*135.765*	*0.323*	*3.361*	*0.001*
w_{ji}	*-0.344*	*0.065*	*-0.636*	*-5.272*	*0*
power	*-107436.721*	*17284.063*	*-0.498*	*-6.216*	*0*

Table 4.5. Ex-post analysis of the cost allocation in the CO scenario. The dependent variable is u_i^t

Explanatory variables	Unstandardized Coefficients		Standardized Coefficients	t	Sign.
	B	Errore std.	Beta		
(Constant)	*12640.162*	*1984.766*		*6.369*	*0*
q_i	*4035.225*	*624.423*	*0.446*	*6.462*	*0*
Distance (km)	*1.857*	*0.375*	*0.2*	*4.953*	*0*
$\lvert D_i \rvert$	*-2160.643*	*267.86*	*-0.541*	*-8.066*	*0*
w_{ji}	*-0.321*	*0.129*	*-0.21*	*-2.497*	*0.013*
power	*-60843.952*	*34100.853*	*-0.1*	*-1.784*	*0.075*

Table 4.6. . Ex-post analysis of the cost allocation in the NC scenario. The dependent variable is m_i^t.

5 Discussion

5.1 Lessons from the review

Rural policies interact within a complex social-ecological and economic environment, the so-called SES. The literature highlights two reasons to embed a collective approach in the formulation of rural policies dealing with natural resource management.

First, many ecological processes exhibit thresholds and spatial aspects. If these elements are not explicitly addressed, the policy and the incentives they set can be ineffective despite the effort. This issue has generated the literature on AB. Second, natural resource management often leads to benefits that accrue to the farmer themselves, even though often these benefits exhibit different degrees of non-rivalry and non-excludability. The agricultural economics literature has started addressed this issue, cooperation and coordination are accounted in some analysis, but in most of the cases only profitability of the cooperation is addressed, whereas the stability of such arrangements have not be taken into account. Also an explicit assessment of the policy design seems to be lacking. Consider also that most of the problems and the models are spatially explicit and thus highly case-dependent, so that their results are difficult to generalize. However, the literature on IEA has applied and developed concepts and tools from the cartel stability literature that have enabled an analytical account of the stability of the cooperation and the endogenization of the coalition size. This entails a simplification with respect to the spatial issues but a gain in terms of generalizability of the results.

Finally distributional issues matter when players interact with each other. This has been analysed theoretically, but also found in experimental analysis on groups dealing with natural resource management.

From the literature review some conclusions that are the basis for the analysis that have followed are drawn. First, it seems rational, in certain conditions to embed a collective approach for the management of natural resource. Second, this approach can be implemented by means of MPRs. Third, the distributional effect of the policy scheme should be addressed since distributional issues are an important aspects to take into account.

5.2 Summary of results

Here I briefly present the main results of the thesis (see also **Table 5.1**).

Section 3 deals with the stability of coalitions and how the design of policy schemes can have an effect on the emerging group of co-operators.

The main findings in the case study on public good are the following. A coalition emerges even in the absence of subsidy but its size is be rather limited. The coalition size is also not affected by a subsidy in case the incentives do not discriminate between members and non-members of the coalition. On the other hand, a heterogeneous payment (that discriminates between members and non-members of a coalition) does increase the size of the stable coalition, and the total public good provision is quadratically related to the payment level. By combining these results I find that is likely that a collective approach is more effective then having a traditional payment when the population of farmers affected by the public good provision is relatively small, and the benefits are relatively low. Finally, the association of a MPR to the coalition subsidy (the way by which in most of the case a collective approach is actually implemented) increases the range of parameters for which a discriminatory payment is more effective. In contrast to much of the existing literature on cooperation in rural areas, I endogenize the size of the coalition, which has enabled to shed some light on the possibility of policies aimed at fostering the coordination of farmers on natural resource management.

In the second case study I analyse the possibility that a government provides subsidies to cover part of the construction costs of collective reservoir, a club good, to decrease the pressure on groundwater resource. Applying findings of previous studies I assess the conditions in which government intervention is needed to foster the emergence of the club. More specifically, in case only one club is possible to form, if the population of farmers is small, the club subsidy helps to reduce the critical coalition size for the club to become relatively more profitable than groundwater exploitation. Moreover, if the population of farmers is above the optimal club size, and the regulator wants to expand the club size, the incentives must be associated with a MPR, otherwise the subsidy actually reduces the club size. Furthermore, in case of multiple clubs the combination of a payment and of a MPR that artificially sets the minimum average cost for the club of size equal to the MPR ensures the non-emptiness of the core.

In the third case I reformulate in term of CGT a standard model of AB. The reformulation of the model enables the assessment of the stability of the group of players whose cooperation is boosted by the policy incentives. The application of the core to the problem suggests that setting relatively high MRP is actually cheaper than providing subsidies that incentivise even smaller arrangement. The reason is that the value of the grand-coalition must be big enough to cover all the potential competing claims of the players, that in such an example are represented by the payments dedicated to smaller groups. The lower the opportunity cost of fully cooperating (and thus the lower the AB that incentivized smaller groupings), the lower is the necessary value of the grand-coalition to satisfy the player's claims.

After the coalition formation analysis I address the problem of the effect of the MPR on the distribution of the benefits.

In the first part I assess the SV of an irrigation water management project that is incentivized by rural polices. In such a case, the policy interacts with an environment in which benefits exhibit club good type of benefits. In this setting I assess the distributional impact of MPRs. The results of the theoretical analysis show the effect of MPRs on potential worth sharing in a common project. Such rules affect the opportunity costs of joining a grand-coalition, so that the bargaining power of the players is also affected. Setting relatively high MPR reduces the value of the sub-optimal coalitions, which can no longer access public financial support, and it increases the relative advantages of full cooperation in the grand-coalition. The SV distributes the worth of the grand-coalition taking into account all the possible arrangements other than the grand-coalition that can emerge, reporting a value that reflects the contributions that each player provides to the grand coalition. The two rules (based on a minimum total volume and a minimum number of players) affect the SV of the players in different ways. An initial increase in the q-rule tends to depress the SV of the smaller players and to benefit the bigger players as long as the smaller players are the ones that are relatively more affected by the cost imposed by the q-rule. Further increases re-equilibrate the distribution after the big farm no longer participates in the policy and its access to the financial support is granted only by cooperating. On the other hand, a rule on the number of players tends to favour the smaller players, since the most significant benefit of cooperation, the participation in the RDP, is granted only by cooperating with other players. Moreover, while more accurate and different analyses are needed, results seems to suggest that farm *A*, the smallest, yet the one with the steepest water revenue function, is the most attracted by the policy, since it experiences the highest gains from enrolling in the policy. This clearly depends on the heterogeneity of the group of players. Results are difficult to compare with other studies, except for those straightforward, like the effect of policy support on optimal water quantity and profits. However, on a different topic, namely climate change negotiations, Kesternich (2015) highlights findings that can be used to qualitatively validate the same results that I find here. Indeed, Kesternich (2015) finds that even in the case of climate change negotiation, small players/countries (from an economic point of view) rather have high minimum n-rules that more likely empower them. The opposite occurs for big players, which would rather have low level for n-rules and high level for q-rules. The SV seems to capture these directions.

The empirical part of the analysis is an attempt to parameterize on an actual case the effect of the introduction of MPR associated to a subsidy for the construction of a collective reservoir. Even in this case, the SV is the solution that has been chosen to have an estimate of the distributional impact of the policy. In contrast to the previous case, I assessed how the distributional impact is affected by spatial location of the farms in a real landscape, and by different social environment. The results further underpin the idea that MPR can have a distributional effect. In addition, such a distributional effect is affected by the social environment and by the geography of the SES. MPR have a greater effect on the benefit distribution in a collaborative environment rather than in a non-collaborative. However, setting relatively high MPR makes the two systems alike, since in both cases all the farms are needed to gain the policy support, and there is less room for the imposition of individual claims.

Case studies	**Stability**		**Distributional effects**	
	Effect of subsidy	*Effect of MPR*	*Effect of subsidy*	*Effect of MPR*
Public good	It increases the contribution to public good It increases the coalition size only in case of discrimination between coalition and free-riders	It increases the scope for a collective approach		
Club good	It could both increase and decrease the club n-size according to N and MPR	It increases the n-size It ensures the non-emptiness of the core		It increases the relative advantages of full cooperation in the grand-coalition Q-rule tends to depress the SV of the smaller players and to benefit the bigger players N-rule tends to favour the smaller players
Private costs	It increases the coalition size of farms enrolling land in an AEP, but in case is associated to MPR	It increases the cost-effectiveness of AB (related to the non-emptiness of the core)		

Table 5.1. Summary of main results

5.3 Limitation and further research

A number of limitations apply to the analysis of the stability of the coalitions. First most of the issues here at stake have a spatial dimension that I purposely omit from the analysis to have a more analytical account. However network theory can be used to structurally frame the spatial dimension of the problem by e.g. modelling the spatial relations of farms and their land allocation decision. Network formation models, and the stability of networks have been developed by the literature (e.g. Jackson and Wolinsky, 1996). The use of network to model spatial relations, and the application of network formation model, seems a strategy that could introduce a more powerful empirical background and thus it can be employed for an ex-ante analysis of collective conditionality constraints of actual policy setups.

Second, in the thesis I separately analyse public good, club good and private costs. However, it is possible to account for all these type of situation in a unified manners as in, for example, Brau and Carraro (2011) where in their model a parameter determines the extent of the excludability of the benefits of the coalition. Such an extension would certainly improve the generalizability of the results.

However, the most promising extension of the current analysis is represented by the use of principal-agent models and incomplete information. In the literature several analysis are available that could be used to further extend the investigation of collective approaches in rural policies. For example Holmstrom (1982) analyses moral hazard in teams deriving a multilateral contract in case only aggregate output is observable. Cooperation among agents, through help (Itoh, 1991) or through bilateral contracts (Holmström and Milgrom, 1990) have been also the focus of contract theory. Finally the concept of the core has been applied to incomplete information setup (Vohra, 1999).

Limitations apply also to the analysis of the distributional effect of collective approaches in rural policies. CGT, and especially the SV, are not easy to scale up given their combinatorial nature. The SV needs to address all of the possible orderings of the players; the core requires all of the possible combinations of players to define the disequations that determine it. This implies clear and detailed information on the characteristic function of the game for all of the possible coalitions. On the other hand methodological advancements have been employed to apply CGT to larger systems, such as the meaningful spatial aggregation of units (Young et al., 1982), the modification of the SV to account for different probabilities of coalition formation (Loehman et al., 1979), and the sampling approach I used in section 4.3 to compute the SV (Castro et al., 2009).

Furthermore, I use the SV in positive manner to assess the distributional effects of a policy rule. The SV distributes benefits according to the power of the players, and the fairness of the final allocation could well be disputable. The SV is only one of the possible ways to share benefits across players proposed by CGT. For example, the Nash-Bargaining solution, and its extension to the n-player case (Nash-Harsanyi solution) gives more weight to the singleton payoffs (the disagreement points). Moreover, a number of indices have been developed and applied to test the fairness of different allocation rules (Madani and Dinar, 2012). A potential extension of the current paper is to compare the SV allocation with other allocation rules, and experimentally test them to assess which is the preferred allocation rule.

5.4 Policy recommendation

The analysis carried out in this thesis is largely theoretical, even though in section 4 I parameterized the models as much as possible on actual data. Despite this, the results confirm, and further specify, the suggestions by Epanchin-Niell and Wilen (2014) that embedding collective conditionality constraints into rural policies can help farmers coordinating. This also adds some justification for the formulation of AB, whose main rationale is the effectiveness of policies aimed at biodiversity conservation when land is scattered in multiple properties, but that did not consider the possibility that such a conservation yields benefits to the rural economy (Parkhurst et al., 2002).

Beside the analysis of clubs and of the distributional effect of MPR that are inspired by measure 125 of the 2007-2013 E-R RDP, the other polices that are simulated are a generic representation of potential measures that embed a collective approach. So for instance the agri-environment-climate payment for the application of buffer strips in the E-R RDP is increased by 30% in case of a collective implementation but the justification for such an increase is the emergence of transaction costs related to the coordination of the farmers. The 125 measure of the 2007-2013 E-R RDP provides subsidies aimed at building collective reservoirs, with the goal of reducing pressure on groundwater, subject to two types of collective conditionality constraints. Its application by the CBRO represents an interesting anecdotal example of a successful implementation of a collective approach. Facing such general measure, the CBRO functions as a bridge institution between the regional administration and the local SES. Given the closer look at the SES variables, the CBRO is able to effectively coordinate farmers, to identify the potential location, and to select and to promote the most promising projects (collective reservoirs, in such a case). As it will be highlighted in the next paragraphs, this seems a virtuous example to take lessons from. The actual policies that have embraced some forms of a collective approach, to the best of my knowledge, seem to have mostly addressed the issue of threshold and spatial effects in environmental processes. A more complex understanding of the type of benefits that natural resource management yields could be explicitly introduced in the policy formulation. Even in the literature, except for the obvious case of irrigation water, the value of ecosystem services for agriculture is barely taken into account (Cong et al., 2014).

To further deepen the previous point, these results point out that indeed introducing collective conditionality constraints is a strategy worth exploring but that the policy elements (payment and MPR) should be carefully designed depending at least on the type of benefits delivered by the action subsidized. Indeed subsidy and MPR have different effect according to the type of benefits (public/club good) and SES variables. For instance, increasing the subsidy level does not affect the coalition in a public good situation, whereas the effectiveness of a heterogeneous payment depends on the population of farmers. Also the need for policy intervention on a club good depends on the population that is affected. According to the population, the subsidy can cause the formation of club (relatively small N) or the reduction of the club n-size (relatively larger N). Moreover, the MPR increases the effectiveness of the measures. In the public good case a MPR increases the conditions that make a collective approach relatively more effective than a traditional AEP. The combination of subsidy and MPR in a club good enables the increase in the n-size of the club. Setting relatively high MPR reduces the subsidy required for the core to be non-empty in the case of the AB. Altogether, the differences in the effect of subsidy levels and MPR ask for a proper formulation of policy that explicitly addresses the type of benefits that the action subsidized deliver to the rural population.

In addition, the endogenization of the coalition enables to account for some of the specific SES variables that matter for the uptake of policies with collective conditionality constraints. In both the public good and in the club good, the size of population of farmers is a key variable to take into account, whose effect is also different according to the difference between public and club good. Recall that a collective approach is relatively more effective in the case of public good when the farmer population is relatively small; that also the formation of a club (collective reservoir) and the effect of club subsidy depends on the population affected. All these issues translate in the need of a spatial account of the extent of both the benefits and the cost of the actions subsidized. For instance in the public good case, it means to have an estimate on the critical mass of green infrastructure required to attract rural tourism, and to what extent (spatial and monetary) tourism rewards the local economy. In the case of club good, it would be important to know how the spatial distribution of the farms affects the congestion costs of the club.

Furthermore, as the ostromian literature has shown, distribution of benefits matters when interactions among players are at stake. Thus an ex ante analysis of the distributional effect of collective conditionality constraint seems to be relevant.

To summarize, a collective approach is worth exploring but that it is likely that requires a detailed knowledge on the local conditions to be effective. Such knowledge could be gained by the use of bridging institutions that are positioned in-between the region and the local SES, and that have more detailed knowledge on the SES variables. Such institutions, like the example of the CBRO in E-R with respect to measure 125 of the RDP, can affectively help the coordination of the individual efforts, and the selection of the most promising collective projects.

6 Conclusions

The collective approach toward natural resource management in agriculture is increasingly gaining attention, by both the literature and policy makers. In the thesis I analyse the implementation of collective approaches in rural policies aimed at natural resource management. More specifically, I analyse how two design elements of this type of policies, collective conditionality constraints and subsidy levels, affect the 1) emergence of cooperation among farmers and 2) the distribution of the benefits. In the analyses I address the effect of these policies in a range of situations, namely in case the action subsidized by policy is a public good, a club good, or only a private cost (and thus cooperation is purely linked to the implementation of the policy). The distributional effect is addressed only in the club good case.

Most of the agricultural economics literature has addressed such an issue by comparing the outcomes of uncoordinated actions with the outcome generated by a cooperative approach, taking as exogenously given the size of the group of cooperating farmers. The thesis is a step in attempting to endogenize the size of the coalition, and thus to have a more specific assessment of the policy elements that could be used to foster cooperation related to natural resource management.

The results show that indeed the proper use of collective conditionality constraints associated to subsidies can improve the cooperation of farmers and thus leading to more effective agri-environmental policies. Formulating AEP that discriminates between co-operators and free-riders, and associating to such a payment a MPR, is relatively more effective than the traditional AEP. Subsidy on club construction costs could use an AEP to increase the n-size of the club. In an AB, a relatively high MPR enables to set a relatively lower AB level. However, MPR are not neutral with respect to the distribution of the benefits, and different types of rules could have opposite effect on it.

The main limitations are linked to the nature of the current analysis, which is mostly theoretical and anyway focused on highly simplified situations (which, however, is common to the vast majority of literature in this field). For example the spatial dimension has been treated only marginally, while it is crucial for environmental management. The use of network formation models could improve the current analysis toward a more empirical ex-ante analysis of collective conditionality constraints. Moreover, perfect information is assumed, whereas a number of studies have addressed moral hazard in teams that might as well as being an important extension of the analysis.

Despite the limitations, some relevant policy recommendations arise from this study. The instruments to implement the collective approach should be properly designed taking into account the type of benefits that the action subsidized deliver to the rural areas and the context (e.g. size and type of the population) for implementation. Thus an accounting of the type of the benefits and the spatial coverage of the beneficiaries generated by environmental management should be made. Distribution matters, and more attention should be paid, by both policy makers and by the literature, to distributional effect associated to the policy environment. "Endogenization" of distributional effects, incentives to coalition formation and type of good produced also make explicit the different role of policies, which could be either a starter of privately profitable initiatives, a way of providing incentives to the provisions of privately unprofitable public goods, a way of overcoming transaction costs or an instrument to set the provision of the good at the right size and scale. This analysis also points at the issue of interaction between policies and economic agents besides affecting markets through price setting. A general policy recommendation that emerges is that the regional administration should provide a general framework in which a collective approach is envisioned, and that bridging institutions help the coordination of agents and the implementation at the SES levels.

The analysis suggests that more knowledge from both the theoretical and empirical side on a number of issues are required to increase our understanding of the potential impact of, and hence to properly design, such policies. From the theoretical side, the further application of game theory to agricultural economics issues would certainly help the ex-ante analysis of the general effect of rural policies with and without collective conditionality constraints. Theoretical and abstract models are certainly important for having an overview of the potential impacts, but cooperation and the formation of coalitions most likely impose an empirical accounting of the social, economic and ecological conditions in which such policies interact. For instance transaction and coordination costs are a burden that if not properly addressed could erode the benefits from cooperation and ultimate could prevent coalitions from emerging. The social environment, equity/distributional considerations, trustworthiness of institutions and among players, potential of effective communication are key factors that determine the actual emergence of cooperation.

To conclude, it seems that the collective approach for natural resource management is a strategy that deserves higher attention and policy effort. However, it should not be taken lightly or naively implemented, as the "sophistication" of mechanisms also increases the scope for unexpected policy outcomes. A more aware implementation of such strategy also requires a greater, inter-disciplinary, effort for research, towards a proper understanding of actual effects of real life policy options and coordination mechanisms.

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7 Appendix

7.1 Appendix of section 3.2.1

Equation **(3.10**) can be reformulated as follows:

$$
\begin{aligned}
\pi_f(s-1) &= b\left(\frac{b}{k}(s-1)^2+(N-s+1)\frac{b}{k}\right)-\frac{1}{2}k\left(\frac{b}{k}\right)^2 = \\
&= \frac{b^2}{k}\left((s-1)^2+N-s+1-\frac{1}{2}\right) = \\
&= \frac{b^2}{k}\left(s^2+1-2s+N-s+1-\frac{1}{2}\right) = \\
&= \frac{b^2}{k}\frac{1}{2}\left(2s^2+2-4s+2N-2s+2-1\right) = \\
&= \frac{b^2}{k}\frac{1}{2}\left(2s^2-6s+2N+3\right)
\end{aligned}
$$

7.2 Appendix of section 3.2.2 (A)

To find the stable coalition in the case of AEP, start from $\pi_f(s-1)$:

$$\pi_f(s-1)=b\left(\frac{b(s-1)+p_m}{k}(s-1)+\frac{b+p_f}{k}(N-s+1)\right)+p_f\frac{b+p_f}{k}-\frac{1}{2}k\left(\frac{b+p_f}{k}\right)^2$$

which becomes:

$$\pi_f(s-1)=b\left(\left(b(s-1)+p_m\right)(s-1)+\left(b+p_f\right)(N-s+1)\right)+p_f\left(b+p_f\right)-\frac{1}{2}\left(b+p_f\right)^2=$$
$$=\left(b^2(s-1)+bp_m\right)(s-1)+b\left(b+p_f\right)(N-s+1)+p_f\left(b+p_f\right)-\frac{1}{2}\left(b+p_f\right)^2=$$
$$=\left(sb^2-b^2+bp_m\right)(s-1)+b\left(b+p_f\right)(N-s)+b\left(b+p_f\right)+p_f\left(b+p_f\right)-\frac{1}{2}\left(b+p_f\right)^2=$$
$$=bs\left(sb+p_m\right)-sb^2-\left(sb^2-b^2+bp_m\right)+b\left(b+p_f\right)(N-s)+\left(b+p_f\right)\left(b+p_f\right)-\frac{1}{2}\left(b+p_f\right)^2=$$
$$=bs\left(sb+p_m\right)-sb^2-\left(sb^2-b^2+bp_m\right)+b\left(b+p_f\right)(N-s)+\left(b+p_f\right)^2-\frac{1}{2}\left(b+p_f\right)^2=$$
$$=bs\left(sb+p_m\right)-sb^2-\left(sb^2-b^2+bp_m\right)+b\left(b+p_f\right)(N-s)+\frac{1}{2}\left(b+p_f\right)^2$$

I then put $\pi_f(s-1)$ and $\pi_m(s)$ in the stability function:

$$bs\left(bs+p_m\right)+b\left(b+p_f\right)(N-s)+p_m\left(bs+p_m\right)-\frac{1}{2}\left(bs+p_m\right)^2=bs\left(sb+p_m\right)-sb^2-\left(sb^2-b^2+bp_m\right)+b\left(b+p_f\right)(N-s)+\frac{1}{2}\left(b+p_f\right)^2$$

Which after some steps becomes

$$p_m\left(bs+p_m\right)-\frac{1}{2}\left(bs+p_m\right)^2=-sb^2-\left(sb^2-b^2+bp_m\right)+\frac{1}{2}\left(b+p_f\right)^2$$

$$bsp_m+p_m^2-\frac{1}{2}b^2s^2-\frac{1}{2}p_m^2-bsp_m=-2sb^2+b^2+bp_m+\frac{1}{2}b^2+\frac{1}{2}p_f^2+bp_f$$

$$p_m^2-\frac{1}{2}b^2s^2-\frac{1}{2}p_m^2=-2sb^2+b^2+bp_m+\frac{1}{2}b^2+\frac{1}{2}p_f^2+bp_f$$

$$2p_m^2-b^2s^2-p_m^2=-4sb^2+2bp_m+3b^2+p_f^2+2bp_f$$

$$p_m^2-b^2s^2=-4sb^2+2bp_m+3b^2+p_f^2+2bp_f$$

$$b^2s^2-4sb^2-p_m^2+2bp_m+p_f^2-2bp_f+3b^2=0$$

$$b^2s^2-4sb^2-\left(p_m^2+2bp_m-p_f^2-2bp_f-3b^2\right)=0$$

$$b^2s^2-4sb^2-\left(p_m^2+2bp_m-p_f^2-2bp_f-3b^2\right)=0$$

$$s=\frac{4b^2\pm\sqrt{16b^4+4b^2\left(p_m^2+2bp_m-p_f^2-2bp_f-3b^2\right)}}{2b^2}$$

$$s=\frac{4b^2\pm\sqrt{4b^2\left[4b^2+\left(p_m^2+2bp_m-p_f^2-2bp_f-3b^2\right)\right]}}{2b^2}$$

$$s = \frac{4b^2 \pm 2b\sqrt{b^2 + \left(p_m^2 + 2bp_m - p_f^2 - 2bp_f\right)}}{2b^2}$$

$$s^* = \frac{2b \pm \sqrt{b^2 + \left(p_m^2 + 2bp_m - p_f^2 - 2bp_f\right)}}{b}$$

7.3 *Appendix of section 3.2.2 (B)*

By setting *k=1*, the total amount of L becomes:

$$L = \frac{bs + p_m}{k} s + \frac{b}{k}(N - s) = (bs + p_m)s + b(N - s)$$

By setting $p_f=0$ and $p_m>0$ the stable coalition becomes:

$$s^* = \frac{2b + \sqrt{b^2 + p_m^2 + 2bp_m}}{b} = \frac{2b + \sqrt{(b + p_m)^2}}{b} = \frac{3b + p_m}{b} = 3 + \frac{p_m}{b}$$

Substituting *s* into *L* yields:

$$L^e = \left(b\left(3 + \frac{p}{b}\right) + p\right)\left(3 + \frac{p}{b}\right) + bN - b\left(3 + \frac{p}{b}\right) =$$

$$L^e = (3b + 2p)\left(3 + \frac{p}{b}\right) + bN - 3b - p =$$

$$L^e = 9b + 3p + 6p + 2\frac{p^2}{b} + bN - 3b - p =$$

$$L^e = 6b + 8p + 2\frac{p^2}{b} + bN$$

Setting a homogenous payment leads a size of the stable coalition of 3; total protected land is given by:

$$L^o = (bs + p)s + (b + p)(N - s) =$$
$$L^o = bs^2 + ps + bN - sb - sp + pN$$
$$L^o = bs^2 + bN - sb + pN$$

and after substituting *s*=3* becomes:

$$L^o = bs^2 + bN - sb + pN =$$
$$L^o = 9b + bN - 3b + pN$$
$$L^o = 6b + bN + pN$$

When discriminating is convenient? Or when $L^e > L^o$:

$$6b + 8p + 2\frac{p^2}{b} + bN > 6b + bN + pN$$

$$8p + 2\frac{p^2}{b} > pN$$

$$8 + 2\frac{p}{b} > N$$

$$8b + 2p > bN$$

$$p > \frac{1}{2}b(N - 8)$$

Substituting into L^o:

$$\hat{L} = 6b + bN + N\left(\frac{1}{2}b\left(N - 8\right)\right)$$

$$\hat{L} = 6b + bN + \frac{1}{2}bN^2 - 4bN$$

$$\hat{L} = b\left(6 + \frac{1}{2}N^2 - 3N\right)$$

7.4 *Appendix of section 3.2.3*

Profits for coalition members can be written as follows.

$$\pi_m^p = b\left[\left(bs+p_m\right)s+b\left(N-s\right)\right]+p_m\left(bs+p_m\right)-\frac{1}{2}\left(bs+p_m\right)^2 =$$

$$\pi_m^p = b\left[\left(bs^2+sp_m\right)+b\left(N-s\right)\right]+\left(p_m bs+p_m^2\right)-\frac{1}{2}\left(b^2s^2+p_m^2+2p_m bs\right)$$

$$\pi_m^p = b^2s^2+bsp_m+b^2\left(N-s\right)+p_m bs+p_m^2-\frac{1}{2}\left(b^2s^2+p_m^2+2p_m bs\right)$$

$$\pi_m^p = \frac{1}{2}b^2s^2+bsp_m+b^2\left(N-s\right)+\frac{1}{2}p_m^2$$

Also profits for free-riders can be reformulated:

$$\pi_f\left(s-1\right)=b\left(\frac{b\left(s-1\right)}{k}\left(s-1\right)+\frac{b}{k}\left(N-s+1\right)\right)-\frac{1}{2}k\left(\frac{b}{k}\right)^2=\frac{b^2}{2}\left(2s^2-6s+2N+3\right)$$

The coalition of size s=t (with a MPR) is stable as long as $\pi_m^p > \pi_f\left(s-1\right)$:

$$\frac{1}{2}b^2s^2+bsp_m+b^2\left(N-s\right)+\frac{1}{2}p_m^2 > \frac{b^2}{2}\left(2s^2-6s+2N+3\right)$$

$$b^2s^2+2bsp_m+2b^2\left(N-s\right)+p_m^2 > b^2\left(2s^2-6s+2N+3\right)$$

$$b^2s^2+2bsp_m+2b^2N-2b^2s+p_m^2 > 2b^2s^2-6b^2s+2b^2N+3b^2$$

$$2bsp_m+p_m^2 > b^2s^2-4b^2s+3b^2$$

$$b^2s^2-4b^2s-2bsp_m+3b^2-p_m^2<0$$

$$b^2s^2-s\left(4b^2+2bp_m\right)+3b^2-p_m^2<0$$

$$s=\frac{4b^2+2bp_m\pm\sqrt{\left(4b^2+2bp_m\right)^2-4b^2\left(3b^2-p_m^2\right)}}{2b^2}=$$

$$s=\frac{4b^2+2bp_m\pm\sqrt{16b^4+4b^2p^2+16b^3p-12b^4+4b^2p^2}}{2b^2}=$$

$$s=\frac{4b^2+2bp_m\pm\sqrt{4b^4+8b^2p^2+16b^3p}}{2b^2}=$$

$$s=\frac{4b^2+2bp_m\pm\sqrt{4b^2\left(b^2+2p^2+4bp\right)}}{2b^2}=$$

$$s = \frac{4b^2 + 2bp_m \pm 2b\sqrt{b^2 + 2p^2 + 4bp}}{2b^2} =$$

$$s = \frac{2b + p \pm \sqrt{b^2 + 2p^2 + 4bp}}{b} =$$

$$s = 2 + \frac{p}{b} \pm \sqrt{4 + 8\frac{p^2}{b^2} + 16\frac{p}{b}}$$

$$(7.1)\ \ 2 + \frac{p}{b} - \sqrt{4 + 8\frac{p^2}{b^2} + 16\frac{p}{b}} s < 2 + \frac{p}{b} + \sqrt{4 + 8\frac{p^2}{b^2} + 16\frac{p}{b}}$$

The range of potential stable coalitions of size s=t (with a MPR) has a lower and an upper bound. Note however, that as a lower bound, the MPR is stable as long as $t > s^{*p} = 3 + \frac{p_m}{b}$. Such a lower level is always binding on the lower level set by equation **(7.1)**:

$$2 + \frac{p}{b} - \sqrt{4 + 8\frac{p^2}{b^2} + 16\frac{p}{b}} < 3 + \frac{p}{b}$$

$$-\sqrt{4 + 8\frac{p^2}{b^2} + 16\frac{p}{b}} < 1$$

7.5 *Appendix of section 3.4*

The optimal club is given by:

$$\max \pi_i = f\left(q_i\right) - \frac{1}{n} K\left(nq_i\right) =$$

$$= -\frac{1}{2} aq_i^2 + bq_i - \frac{1}{n}\left(\frac{1}{3} c\left(nq_i\right)^3 - d\left(nq_i\right)^2 + enq_i\right)$$

$$= -\frac{1}{2} aq_i^2 + bq_i - \left(\frac{1}{3} cn^2 q_i^3 - dnq_i^2 + eq_i\right)$$

The two FOCs are:

$\partial \pi_i / \partial n = 0$ and $\partial \pi_i / \partial q_i = 0$

The first FOC is the following:

$$\partial \pi_i / \partial n = 0$$

$$-\frac{2}{3} cq_i^3 n + dq_i^2 = 0$$

$$-\frac{2}{3} cq_i n + d = 0$$

$$n = \frac{3d}{2cq_i}$$

$$q_i n = \frac{3d}{2c}$$

Thus the optimal total club size is given by:

$$Q = \frac{3d}{2c}$$

The second one is:

$$\partial \pi_i / \partial q_i = 0$$

$$-aq_i + b - cn^2 q_i^2 + 2dnq_i - e = 0$$

$$-aq_i + b - c\left(\frac{3d}{2cq_i}\right)^2 q_i^2 + 2d\frac{3d}{2cq_i} q_i - e = 0$$

$$-aq_i + b - \frac{9d^2}{4c} + \frac{3d^2}{c} - e = 0$$

$$b - \frac{3d^2}{4c} - e = aq_i$$

Which leads to the optimal q_i^*:

$$q_i^* = \frac{1}{a}\left(b - \frac{3d^2}{4c} - e\right)$$

Thus, $n*$ is given by:

$$q_i = \frac{3d}{2cn}$$

$$q_i^* = \frac{1}{a}\left(b - \frac{3d^2}{4c} - e\right)$$

$$\frac{1}{a}\left(b - \frac{3d^2}{4c} - e\right) = \frac{3d}{2cn}$$

$$\left(\frac{b}{a} - \frac{3d^2}{4ac} - \frac{e}{a}\right) = \frac{3d}{2cn}$$

$$2cnb - \frac{3}{2}nd^2 - 2cne = 3da$$

$$4cnb - 3nd^2 - 4cne = 6da$$

$$4cnb - 3nd^2 - 4cne = 6da$$

$$n\left(4cb - 3d^2 - 4ce\right) = 6da$$

$$n^* = \frac{6da}{4cb - 3d^2 - 4ce}$$

If we introduce a subsidy *(1-α)* we see that the subsidy on the construction costs we see that an increase in the subsidy rate decreases n*:

$$n = \frac{6\alpha\widehat{da}}{4\alpha\widehat{c}b - 3\alpha^2\widehat{d}^2 - 4\alpha^2\widehat{ce}} = \frac{6\widehat{da}}{4\widehat{c}b - \alpha\left(3\widehat{d}^2 + 4\widehat{ce}\right)}$$

7.6 Appendix of section 4.2.2

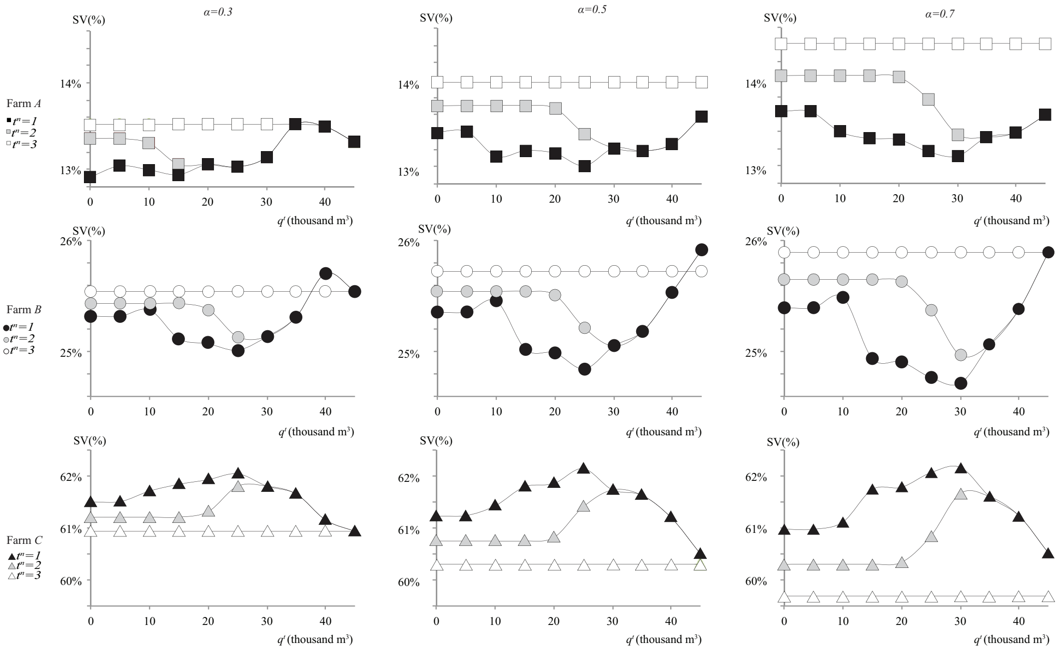
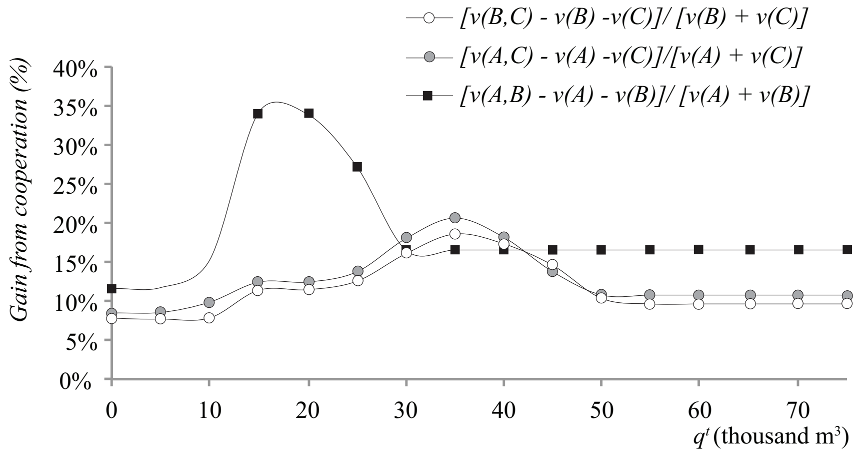


Figure 7.1. Sensitivity analysis on share of financial support, q-rule, and n-rule



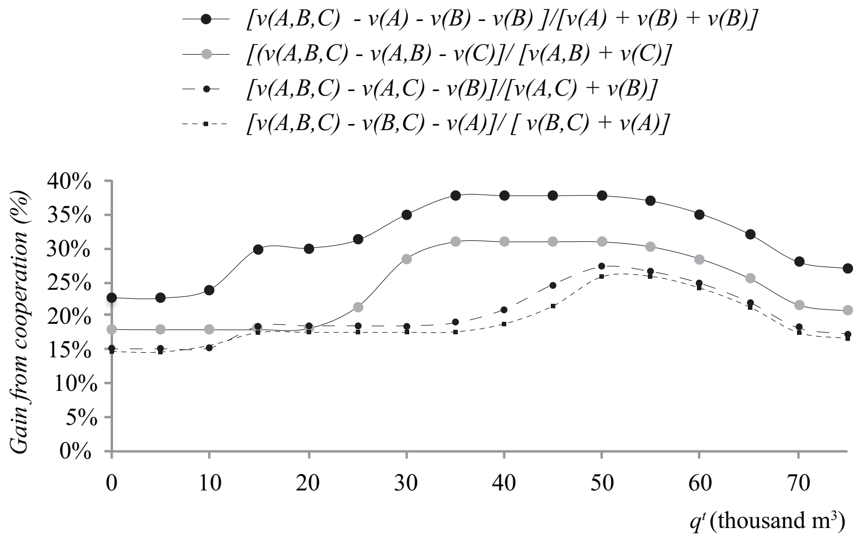


Figure 7.2. Gains from cooperation for any possible arrangement

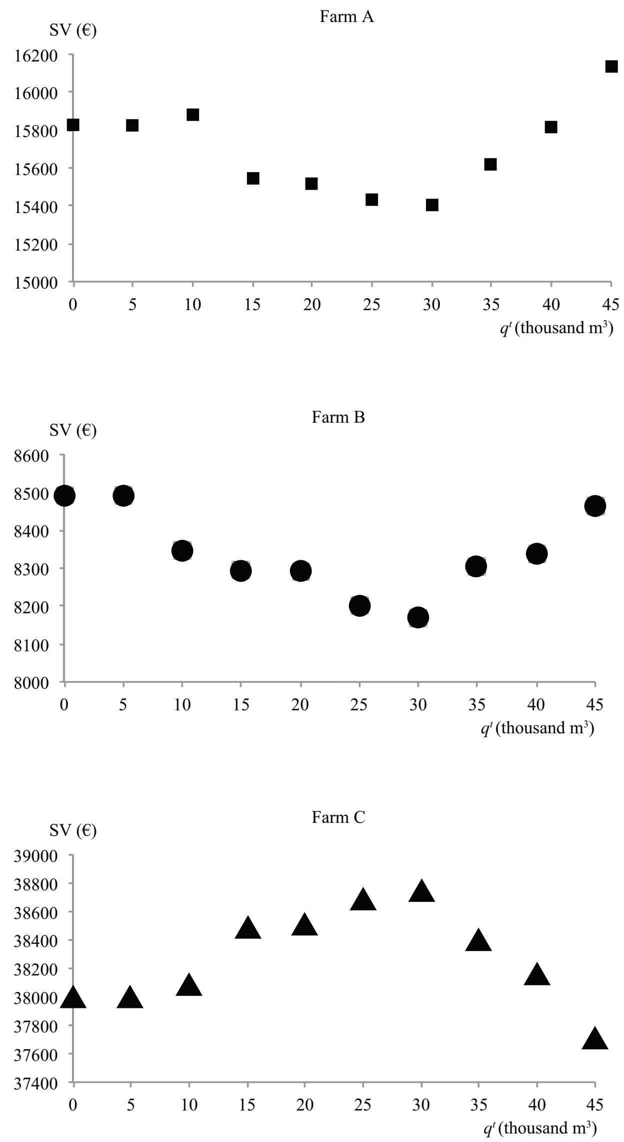


Figure 7.3. Absolute values of Shapley value of the three farms for *α=0.7*, for different values of q-rule