Viable coalitions in open access

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Abstract

This article gives insights on the complex balance between coalitions structure, resource state or dynamics and agents' heterogeneity to avoid bio-economic collapses. A model bringing together coalition games and a viability approach is proposed to focus on the compatibility between bio-economic constraints and an exploited common stock dynamics. It is examined to what extent cooperation promotes sustainability. Based on the Shapley value, a measure of the marginal contribution of the users to the sustainability of the resource is proposed. It suggests that the stability of the grand coalition occurs for large enough stocks. By contrast, for lower levels of resource, the most efficient user plays the role of a dictator.

Keywords: renewable resource, dynamic game, coalition, maxmin strategy, shapley value, viability kernel.

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1 Introduction

This paper deals with the cooperation among users harvesting a renewable resource. According to recent studies (MEA, 2005), biodiversity and exploited renewable resources are under extreme pressure worldwide. Hence sustainability is nowadays a major concern of international agreements and guidelines to fisheries management (ICES, 2004). In this context, exploited biodiversity management involves restoration and conservation objectives, with ecological and economic dimensions including the identification of desirable levels of stocks and profitability from catches. It inevitably raises the question of the number of active potential users of the resource and the way they can cooperate. To avoid possible future collapses of the stocks, catches and rents, we need to determine the conditions under which cooperation can be sustainable.

Game theory modeling provides some important insights on strategic interaction between users exploiting a renewable resource. In particular, the relationship between the number of active agents and the sustainability of the involved stock has been studied in static non cooperative game by Mesterton-Gibbons (1993) or Sandal & Steinshamn (2004) in presence of users differing with respect to their efficiency in terms of harvesting cost. These models both show how the larger the stock, higher the number of active

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players is. The question of coalitions has also received an important attention in this context of renewable resource management. What distinguishes renewable resources coalition game from many other coalition games is that major externalities occur. A particular attention has been paid to coalition issues in fisheries economics. The need for the research of cooperative fisheries management arises from the current practice of international negotiations and implementation of multi-country fisheries agreements. In this context, the formation of coalition has been both analyzed in cooperative games and non-cooperative games. The cooperative game theory literature deals with the allocation rules of the cooperation benefits between the members of coalition using the characteristic function games (c-games). These sharing rules include Shapley value (probably the most used), nucleolus and tau-value (Lindroos, 2004b; Kronbak & Lindroos, 2007; Li, 1999). In this literature, of particular interest is the question raised by the stability of the coalition and especially the grand coalition. The non-cooperative game theory literature focuses on the endogenous formation of coalitions and coalition structure using a partition function game taking into account externalities across the coalitions (Bloch, 1996; Yi, 1997; Finus, 2001). Pintassilgo (2003) derives general results regarding the stability of the coalition structures in straddling stock fisheries. In the presence of positive externalities, the grand coalition is not stable. Using the static Gordon-Schaefer bioeconomic model, Pintassilgo & Lindroos (2008) show that complete non-cooperation is the only equilibrium when at least three symmetric players are concerned.

Our paper questions the shape and size of coalitions with respect to sustainable requirements for the exploited renewable resource. Although our work is in direct line with the models of the literature, it gives new insights by considering a dynamic game focusing on viability constraints. Thus our model differs in several ways. First our approach is dynamic in the sense that the analysis is not restricted to steady states and equilibrium yield. Second, a viability viewpoint is adopted to cope with sustainability. The viability (or viable control) approach does not strive to identify optimal or steady state paths, but rather aims at identifying the conditions that allow desirable objectives or constraints to be fulfilled over time, considering both present and future states (Pezzey, 1997; Baumgartner & Quaas, 2009; Bene et al., 2001). As emphasized in DeLara & Doyen (2008) or Martinet & Doyen (2007), viability is closely related to the maximin (Rawlsian) approach with respect to intergenerational equity. Viability may also allow for the satisfaction of both economic and environmental constraints and is, in this respect, a multi-criteria approach. Viability analysis has been applied to renewable resources management and especially to fisheries (see, e.g. Bene et al. (2001); Eisenack et al. (2006); Martinet *et al.* (2007), but also to broader (eco)-system dynamics (Cury et al., 2005; Doyen et al., 2007; Bene & Doyen, 2008). Relationships between sustainable management objectives and reference points as adopted in the ICES precautionary approach are discussed in DeLara et al. (2007). Here the viability framework allows us to exhibit the conditions under which coalitions can fulfill positive profitability and conservation objectives along time, considering both present and future states of the renewable resource system.

The paper is organized as follows. Section 2 is devoted to the description of the dynamic bio-economic model together with the profitability constraints. Section 3 provides the results related to the shape of the viable coalitions with respect to the level of the resource. The contribution of the agents to the viability is also analyzed using the minimum number of active players and the Shapley value of the game. The last section concludes. All the proofs are available upon request or can be found in http://cahiersdugretha.u-bordeaux4.fr/2009/2009-15.pdf.

2 The dynamic model

Following Conrad & Clark (1987) and DeLara & Doyen (2008), the dynamics of a renewable resource stock $x(t) \in \mathbb{R}_+$ is given by

$$x(t+1) = f(x(t) - h(t)), \qquad t = 0, 1, ..., T, \tag{1}$$

where catches $h(t)$ occur at the beginning of the period. The natural resource productivity is represented by f possibly non linear. We denote by K the capacity charge of the resource defined by

$$K = \sup(x \geq 0, f(x) \geq x).$$

We consider that the resource is exploited by n agents, implying an amount of harvest given by

$$h(t) = \sum_{i=1}^{n} e_i(t)x(t)$$

with $e_i \in [0,1]$ standing for the effort (or harvesting mortality) of each agents $i \in \{1, .., n\}$. Since take-off can not exceed resource stock, a scarcity constraint holds:

$$0 \leq h(t) \leq x(t), \tag{2}$$

implying a constraint on the effort

$$\sum_{i=1}^{n} e_i(t) \leq 1.$$

Following Clark (1990), the rent of each agent i is defined by:

$$\Pi_i(x(t), e_i(t)) = pe_i(t)x(t) - c_i e_i(t),$$

where c_i measures the cost per unit of effort and the price p of the resource is assumed to keep constant. The rent is positive for each agent i when the stock is larger than the the zero-rent level (or open access stock) namely

$$x(t) > x_i^{\text{OA}} = \frac{c_i}{p}.$$

Following Mesterton-Gibbons (1993), we assume that the agents are heterogeneous in the sense that they differ in their cost:

$$c_1 < c_2 < .... < c_{n-1} < c_n,$$

or equivalently in their open access stocks

$$x_1^{\text{OA}} < x_2^{\text{OA}} < .... < x_{n-1}^{\text{OA}} < x_n^{\text{OA}}.$$

It is worth noting that two kinds of externalities occur in this game as every agent may alter both the current catches (and rents) of others agents by the scarcity constraint (2) and also the future catches of agents through harvesting and dynamics (1) which impact the stock for the next period.

Sustainability problem: Following Pezzey (1997); Baumgartner & Quaas (2009); Bene et al. (2001), the sustainability of the system is grasped through constraints to satisfied along time, especially profitability goals. In our multi-agent framework, the dynamic problem that we handle is to determine coalitions $S \subset \{1,\dots,n\}$, harvesting strategies among the coalition $e_i(t),\ i \in S$ and a stock path $x(t)$ which ensures that the aggregated rent of the agents i belonging to the coalition S remains strictly positive, i.e.:

$$\sum_{i\in S} \Pi_i(x(t), e_i(t)) > 0, \qquad t = 0, 1, ..., T$$

Cooperation among a group of players corresponds to the establishment of a management organization with the purpose of managing and protecting the resource stocks jointly. Such a profitability constraint entails the following resource viability requirement captured by the critical bio-economic level x^S

$$x(t) > x^S = \min_{i\in S} x_i^{\text{OA}}.$$

The present paper intends to give insights on the shape and size of the coalition S regarding the initial value of the stock x_0, the resource dynamics f, the economic context (c and p) and these sustainability goals.

Viable states and viability kernel: To achieve this, we define the viability kernels $\mathrm{Viab}_S(t)$ for a given coalition S through backward induction inspired by dynamic programming. First, at the terminal date T, we set

$$\mathrm{Viab}_S(T) = \left\{x \mid x > x^S\right\}$$

For any time $t = 0, 1, ..., T-1$, we compute the viability kernel $\mathrm{Viab}_S(t)$ at time t from the viability kernel $\mathrm{Viab}_S(t+1)$ at time $t+1$ as follows:

$$\mathrm{Viab}_S(t) = \left\{ x > x^s \;\middle|\; \begin{array}{c} \exists e_i \geq 0,\ \forall i \in S,\ \sum_{i\in S} \Pi_i(x, e_i) > 0 \\ f\left(x(1 - \sum_{i\in S} e_i - \sum_{j\notin S} e_j)\right) \in \mathrm{Viab}_S(t+1) \\ \forall j \notin S,\ \forall e_j \geq 0 \text{ s.t. } \Pi_j(x, e_j) \geq 0 \end{array} \right\}$$

The previous definition stresses the fact that the agents among the coalition cooperate for sustainable profitability goals applying both in the present and the future while the outsiders of the coalition act as singleton and are myopic regarding profitability goals. When the users of the resource cooperate within a coalition, the positive profitability condition holds for the whole coalition. Let us remark that due to the assumption of a linear cost function, the rent of the coalition is maximized when the most cost-effective player is the only harvester. The myopic behavior of the outsiders can encompass several strategies including optimizing, inertial ones which are potentially dangerous and risky for the resource.

A simple game formulation: The previous geometric definition of viability kernels can be associated with the following "'maxmin"' (supinf) functional formulation which points out the "simple" (0 or 1) nature of the game. Let us consider the indicator function $\mathbb{1}_{\mathrm{Viab}_S(t)}(.)$ defined by:

$$\mathbb{1}_{\mathrm{Viab}_S(t)}(x) = \begin{cases} 1 & \text{if} \quad x \in \mathrm{Viab}_S(t) \\ 0 & \text{if} \quad x \notin \mathrm{Viab}_S(t). \end{cases}$$

Such indicator function $\mathbb{1}_{\mathrm{Viab}_S(t)}(.)$ turns out to be the solution of the following maxmin dynamic programming equation:

$$\begin{cases} V_S(T,x) &= \mathbb{1}_{\{x > x^S\}}(x) \\ V_S(t,x) &= \sup\limits_{\begin{cases} e_i,\ i \in S \\ e_i \geq 0, \\ \sum\limits_{i \in S} \Pi_i(x, e_i) > 0 \end{cases}} \inf\limits_{\begin{cases} e_j,\ j \notin S, \\ e_j \geq 0 \\ \Pi_j(x, e_j) \geq 0 \end{cases}} \mathbb{1}_{\{x > x^S\}} V_S\left(t+1, f\left(x(1 - \sum\limits_{i \in S} e_i - \sum\limits_{j \notin S} e_j\right)\right) \\ & \qquad t = 0, 1, .., T-1 \end{cases}$$

Such a formulation also highlights the asymmetric feature between the goals of outsiders-insiders.

3 Results

Hereafter, the stock productivity $f : \mathbb{R}_+ \to \mathbb{R}_+$ is assumed to be continuously increasing $f' > 0$ and to satisfy $f(0) = 0$. We also assume that the open-access stocks x_i^{OA} lie in the part where the resource growths in the following sense:

$$[x_1^{\mathrm{OA}}, x_n^{\mathrm{OA}}] \subset]0, K[= \{x \geq 0,\ f(x) > x\}. \tag{3}$$

3.1 Viable coalitions and states:

Let us first identify the viable stocks through the computation of the viability kernels for every coalition.

Theorem 1 *The viability kernels at time t ($t < T$) are*

- $\mathrm{Viab}_S(t) = \emptyset$ *if* $1 \notin S$
- $\mathrm{Viab}_{\{1,\ldots,n\}}(t) =]x_1^{\mathrm{OA}}, +\infty[$
- $\mathrm{Viab}_{\{1,\ldots,j\}}(t) =]x_1^{\mathrm{OA}}, x_{j+1}^{\mathrm{OA}}[$ *for* $j < n$
- $\mathrm{Viab}_S(t) = \mathrm{Viab}_{\widetilde{S}}(t)$ *for* $\widetilde{S} = \cup_i (\{1...i\} \subset S)$

Theorem 1 identifies what are the size and the composition of the viable coalition of users with respect to the stock of the resource. To illustrate this, consider Table 1 where we can distinguish the viability kernels in the case with three players $n = 3$.

Kernel\Stock x	0	x_1^{OA}	x_2^{OA}	x_3^{OA}	K
$\mathrm{Viab}_{\{1,2,3\}}$					
$\mathrm{Viab}_{\{1,2\}}$					
$\mathrm{Viab}_{\{1\}} = \mathrm{Viab}_{\{1,3\}}$					
$\mathrm{Viab}_{\{2\}} = \mathrm{Viab}_{\{3\}} = \emptyset$					

Table 1: Viability kernels (in black) with three players $n = 3$.

The tragedy of open-access revisited: It turns out that cooperation promotes the viability as the higher cooperation between users is, the larger is the viability domain. In particular, the grand coalition $N = \{1, 2, 3\}$ (social viability) corresponds to the largest viability kernel $]x_1^{\mathrm{OA}}, +\infty[$. By contrast, the smallest viable coalition occurs with singletons. In particular, viability vanishes for singletons $S = \{2\}$ or $S = \{3\}$ since both viability kernels $\mathrm{Viab}_{\{2\}}(t)$ and $\mathrm{Viab}_{\{3\}}(t)$ are empty. Another significant viable coalition is formed by agents 1 and 2. However viability is reduced in this partial cooperation case as $\mathrm{Viab}_{\{1,2\}}(t)$ is strictly contained in $\mathrm{Viab}_{\{1,2,3\}}(t)$. Of interest is the fact that the coalition formed by players 1 and 3 is equivalent to singleton $\{1\}$ emphasizing that the role of player 3 is minor in this case. The Shapley value developed in subsection 3.4 will highlight this idea by computing viability contribution values for the different players.

Agent 1 **is a veto player:** These kernels also emphasize that player 1 is a veto player as its presence is always required for the cooperation to be viable. In other words, as soon as the most efficient user 1 is not a member of the coalition, the associated viability kernels are empty. In particular, the only viable singleton is $S = \{1\}$. Again, the Shapley value developed in subsection 3.4 will give more insights on this veto and dictatorship situations.

3.2 Minimum number of players

Given a stock level x, we define by $n^*(x)$ the minimum number of players in a viable coalition by:

$$n^*(x) = \min\left(|S| \mid x \in \mathrm{Viab}_S(0)\right)$$

where $|S|$ stands for the cardinal of the coalition S.

Using Theorem 1, we derive the following condition

$$n^*(x) = \min\left(j \mid x_1^{\mathrm{OA}} < x < x_{j+1}^{\mathrm{OA}}\ \right)$$

It can be illustrated by a stepwise increasing function. This minimum number of active players in a coalition in our dynamic framework is a generalization of the steady state participation condition of Mesterton-Gibbons (1993).

Let us emphasize that the number of viable players increases with stock. In particular, this suggests that the grand coalition is stable whenever the stock is large enough. This assertions is examined in detail in section 3.4 through the shapley value.

3.3 Viable efforts for the viable coalitions:

The next step of the analysis is to exhibit the viable effort of the members of the coalition. We show that several catch efforts can satisfy the linear inequalities of the system. It means that a flexibility occurs in the decision process. Among these viable choices, one can favor efficient or conservative rules or different trade-offs between ecological or economic performances. In order to prevent the outsiders to collapse the resource and the rents, the coalition has to manage the resource in a way that the outsiders become passive. The coalition has to maintain the resource in its viability domain to guarantee its sustainability. Actually, the coalition achieves this by neutralizing the outsiders in a sustainable way. This neutralization occurs by avoiding every profitability for outsiders and more specifically by maintaining the resource below open-access levels for outsiders. It means that the stock falls below the open access level of outsiders but is still above the open access level of members coalition. In such a context, since all the outsiders of the coalition are passive, the coalition does not have to take into account that it can play against either a coalition formed by the outsiders or against individual outsiders.

3.4 Marginal contribution to viability

We define a Shapley measure of the marginal contribution of agents i belonging to a coalition S to the viability kernel as

$$\mathrm{Sh}_i(x) = \sum_{i \in S \subseteq N} \frac{(|S|-1)!(n-|S|)!}{n!} \left(1\!\!1_{\mathrm{Viab}_S}(x) - 1\!\!1_{\mathrm{Viab}_{S\setminus\{i\}}}(x) \right)$$

Applying for instance Lemma 2 (p 362) in Aubin (2007) for simple games, we obtain the following characterization of Shapley value:

Theorem 2 *For $x \in \left]x_j^{\mathrm{OA}}, x_{j+1}^{\mathrm{OA}}\right[$, we have*

$$\mathrm{Sh}_i(x) = \begin{cases} \frac{1}{n^*(x)} & \textit{for} \quad i \leq j \\ 0 & \textit{for} \quad i > j \end{cases}$$

Consequently, the Shapley value captures the fact that whenever the users are active, they contribute positively and to the same amount to the sustainability of the resource. By contrast, passive players contribute for nothing to the sustainability of the resource. Our approach differs from the cooperative coalition games in which the Shapley value is used to compute the shares of the cooperative rent inside the members of the coalition who have created the surplus. Our measure of the marginal contribution to the viability kernel is more qualitative and relies on the ability of players to maintain a safe exploitation of the resource. Applied to our 3 players' example, it gives the table 2.

Agents $i\setminus$ Stock x	0	x_1^{OA}	x_2^{OA}	x_3^{OA}
agent 1	0	100%	50%	33%
agent 2	0	0	50%	33%
agent 3	0	0	0	33%

Table 2: Shapley values $\mathrm{Sh}_i(x)$ for $n = 3$ players

Therefore, the value of the marginal contribution Sh_i of each user determines whether his participation to a coalition is required or not. Note also that in any case, an equity rule among the active players holds true as the "cake" is shared in $n^*(x)$ equal parts. In particular, when the stock is high enough to ensure the active participation of all players, their contributions to the sustainability of the resource are identical. It means that all the agents have the same power to sustain the stock. This situation requires a global cooperation within a coalition. It turns out that the most efficient users cannot displace the less efficient users. At the opposite, when the initial stock is low and lies in the interval $x \in \left]x_1^{\mathrm{OA}}, x_2^{\mathrm{OA}}\right[$, only the most efficient agent and veto player is active and can contribute to the sustainability of the resource. No cooperation with the other agents is required. An intermediate or partial coalition involving an active contribution of player 2 is viable but the veto player 1 has to be always involved as expected.

Corollary 1 *Agent 1 is a veto player if* $x > x_1^{\mathrm{OA}}$.

This corollary directly stems from the fact that $\mathrm{Sh}_1(x) > 0$ for any $x > x_1^{\mathrm{OA}}$.

Corollary 2 *Agent 1 is a dictator if* $x \in]x_1^{\mathrm{OA}}, x_2^{\mathrm{OA}}[$

This last result is due to the fact that $\mathrm{Sh}_1(x) = 1$ for any $x \in]x_1^{\mathrm{OA}}, x_2^{\mathrm{OA}}[= \mathrm{Viab}_{\{1\}}$.

4 Conclusion

This paper has analyzed the conditions under which cooperation of active heterogeneous users within coalition is required to promote the bio-economic viability of a renewable resource. We have proposed a dynamic model bringing together coalition games and a viability approach to focus on the compatibility between bio-economic constraints and an exploited common stock dynamics. The model allows first to revisit the tragedy of open-access and the seminal work of Hardin as it is showed to what extent lack of cooperation reduces or jeopardize the viability of the whole bio-economic system. Focusing on the grand coalition, it is shown how the usual ”sustainable” (steady) states including the maximum economic yield (MEY) are particular cases of viability. We have also determined the minimum number of viable players expanding the equilibrium approach of Mesterton-Gibbons (1993) and Sandal & Steinshamn (2004) to a more dynamic context. Using Shapley value, we assess the contribution of agent to sustainability pointing out situations of veto or dictator players as in Arnason et al. (2000) or Lindroos (2004a). Such a study stresses the fact that diversification in technologies (ratio costs-catchability) is relevant for high levels of stock while specialization, rationalization and dictatorship situations are well-suited for low resource. This suggests how the grand coalition is stable for large resource levels which reinforces assertions of Pintassilgo (2003); Kronbak & Lindroos (2007) and Lindroos (2004b).

5 References

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