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HERMANN BARDARSON

COOPERATIVE HARVESTING AND CORE ALLOCATIONS IN FISHERIES

Department of Economics
UNIVERSITY OF BERGEN

Cooperative Harvesting and Core Allocations in Fisheries

HERMANN BARDARSON*

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ABSTRACT. The use of renewable resources is examined as a cooperative production game, the focus here being on fisheries. It is shown how pooling and exchange of individual endowments may open for substitutions that generate greater efficiency. We introduce a sharing rule that complies with the core concept, applied to heterogeneous multi-species fisheries with transferable utility.

Key words: Resource management, fisheries, heterogeneity, linear programming, cooperative games, core allocations, substitution possibilities, common property.
JEL classification: Q22, C71.

1. INTRODUCTION

Exclusive owners of marine resources such as fish stocks typically confront suboptimal conditions. The general aim of this study is therefore to introduce a cooperative harvesting game that demonstrates how agents facing such conditions may benefit from shared use of individual endowments. It is known - and follows by definition - that the core efficiently deals with coordination problems between agents (producers) who exploit shared resources. So, the question is: *first*, when can core solutions be guaranteed to exist and *second*, how can such an outcome be computed/implemented in fisheries. Using linear programming we demonstrate how pooling of individual fishing quotas, harvesting capacity and skills results in a vector of dual variables (shadow prices) associated to shared resources. Those prices generates an allocation rule that allows full use of substitution possibilities in heterogeneous multi-agent fisheries.

Common pool fisheries have become associated with ecological degradation and rent dissipation [2], [14]. This pessimistic vision, about resource users' disability to avoid social dilemmas, has generated exclusive property rights in fisheries all around the world. The resulting policy implication may take two forms: either privatization

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*Department of Economics, University of Bergen, Fossw. gt. 6, 5007 Norway; e-mail: Herman.Bardarson@econ.uib.no. My deepest thanks to Sjur D. Flåm for contributions and technical help on this paper. I also thank Oddvar Kaarbøe for useful comments. This work was supported by the Norwegian Research Council (NFR) through the program "Market and Society".

of commons or governmental regulation (or a mixture of both). Resource users who face a common pool resource are thus victims and culprits of an inevitable tragedy when left to themselves.

Experiences from the last decades show how the resulting use of individual property rights in fisheries often causes a tragedy no less severe than that of open access fisheries. The reasons are at least threefold: *First*, the appropriators typically finds themselves into a Prisoners' Dilemma, being locked in fixed problem structures and having to rely on guidance from distant authorities already proven unsuccessful in many contexts [6], [7]. *Second*, most marine fisheries are common pool resources. Exclusive rights are then likely to create incentives for "free riding". *Third*, some users may not possess adequate harvesting technology or skills. By denying others access to own resources such users are blocking substitution possibilities. The result is often overcapitalized and subsidy dependent fisheries, featuring overexploitation of commercially important fish stocks.

Peoples' ability to manage common resources fairly efficiently has often been observed; see for instance [1], [4], [11], [16].[1] Indeed, common property institutions often appears as the only forms of resource management with a proven record of long-term sustainability [16]. A coherent analytical framework that reflects this is still lacking. This paper makes a modest step in that direction. It does so by showing how the core solution concept from cooperative game theory may describe a sharing rule that promotes both efficient and sustainable use of heterogeneous common pool fisheries.

The paper is organized as follows: Section 2 deals with basic theoretical aspects of cooperative production games and demonstrates their applicability in fisheries where exclusive and fragmental exploitation typically leads to wasteful allocation. The analysis adds to the seminal work of Owen [17] by allowing variation in objectives and technologies/skills across agents. Section 3 provides an example where gains from heterogeneous common pool fisheries are manifested. Section 4 concludes.

2. The Production Game [2]

2.1. A Linear Harvesting Game.

We consider static multi-agent, multi-species fisheries where each participating agent $i \in I$ has to decide whether to harvest his share of resource/stock $s \in S$ alone, or to cooperate with others. Let e_{sfi} be the

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[1] This body of literature criticizes property theorists for equating common property with open access in their recommendation of exclusive property rights regimes. While property held in commons has cultural and institutional rules that may result in sustainable use of resources, open access is devoid of these rules.

[2] Game theoretical studies of fisheries have mainly been connected to problems concerning management of transboundary and/or struggling fish stocks (that are found in both the coastal state Exclusive Economic Zone and the adjacent high seas), e.g. [5], [8], [9], [12], [13]. The focus of this study is more general: The cooperative harvesting game yields all situations (both intra-territorial and transboundary) where two or more agents benefit from shared use of resources.

fishing effort undertaken by fleet $f \in F$, operated and owned by agent i, and directed towards species $s \in S$ only (bycatch is not regarded as a problem here). Let q_{sfi} denote i's catch per unit effort from fleet f when harvesting species s.[3] By assuming a small stock effect, as justified in pelagic schooling species,[4] it is reasonable to expect the harvest function of each agent i to be separately linear in the various effort levels e_{sfi}. Net contribution to i from fleet f, when harvesting species s, can then be written as

$$\left[p_s q_{sfi} - c_{sfi}\right] e_{sfi} = \pi_{sfi} e_{sfi} \quad \text{where } \pi_{sfi} := p_s q_{sfi} - c_{sfi}.$$

By treating the price p_s per unit of species s - and the cost c_{sfi} per unit fishing effort - as fixed and exogenous, i's profit from the fisheries becomes a linear functions of his effort vector $e_i = [e_{sfi}]$. Any *coalition* $C \subseteq I$ may, in principle, pool their quotas to have

$$b_{sC} := \sum_{i \in C} b_{si}, \ \forall s \in S$$

of species s, and harvesting capacities

$$\bar{e}_{sfC} := \sum_{i \in C} \bar{e}_{sfi}, \forall s \in S, f \in F.$$

If put to joint use these endowments generate an optimal value

$$v_C := \max_{e_{sfi} \geq 0} \left\{ \sum_{i \in C} \sum_{s \in S, f \in f} \pi_{c_{sfi}} e_{sfi} \mid \sum_{f \in F, i \in I} q_{sfi} e_{sfi} \leq b_{sC} \ \forall s \in S, \sum_{i \in C} e_{sfi} \leq \bar{e}_{sfC} \ \forall s \in S, f \in F \right\}. \tag{1}$$

The characteristic function $C \mapsto v_C$, as defined in (1), generalizes Owen's production game [17] by allowing variation in objectives and technologies/skills across agents.[5]

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[3] Catchability is determined by manifold technical factors (gear, vessel type, know how etc.) and complex socio-cultural relations that may be difficult to quantify. For simplicity, we tacitly assume that all knowledge that affects harvesting skills can be reduced to a single technical coefficient q_{sfi}.

[4] Because large schools of fish are easy to find with modern techniques, catching costs are negligibly reduced when stocks are large. Thus the stock effect can be ignored so that costs depend on output alone [14].

[5] The motivation for using heterogeneous fisheries is to demonstrate that heterogeneity may promote cooperation if it is treated properly in the allocation mechanism. However, it is important to be aware of the fact that heterogeneity in pooling groups is a two-edged sword that often creates incentive problems instead of sustaining cooperation. A case study of both successful and unsuccessful pooling groups in Japanese fisheries contends that while a moderate amount of heterogeneity may support cooperation, too much heterogeneity will create problems [18]. By assuming that individual contributions and share in benefits can be differentiated as implied by the core solution concept, cooperation among heterogeneous agents remains feasible, in any case.

2.2. Implementing Core Allocations in Fisheries. We ask: Can the grand coalition $C = I$ form? More precisely: is the core non-empty? That is, does there exist an imputation $i \to u_i$ such that

$$\sum_{i \in I} u_i = v_I \text{ and } \sum_{i \in C} u_i \geq v_C \text{ for all non-empty } C \subset I.$$

Here u_i denotes the payoff allocated to agent i for ceding its quotas and capacities to the grand coalition $C = I$. Note that property rights are well defined, all data are publicly known, and there are no transaction costs.[6] In order to find core allocations, consider the Lagrangian of the grand coalition

$$L_I(\lambda, e) = \sum_{i \in I} \sum_{s \in S, f \in F} \pi_{sfi} e_{sfi} + \sum_{s \in S} \lambda_s \left[b_{sI} - \sum_{f \in F, i \in I} q_{sfi} e_{sfi} \right] + \sum_{s \in S, f \in F} \bar{\lambda}_{sf} \left[\bar{e}_{sfI} - \sum_{i \in I} e_{sfi} \right].$$

This yields the dual function

$$\begin{aligned} L_I(\lambda) \quad &: = \max_{e \geq 0} \left[\sum_{s \in S} \lambda_s b_{sI} + \sum_{i \in I} \sum_{s \in S, f \in F} \left(\pi_{sfi} - \lambda_s q_{sfi} - \bar{\lambda}_{sf} \right) e_{sfi} + \sum_{s \in S, f \in F} \bar{\lambda}_{sf} \bar{e}_{sfI} \right] \\ &= \begin{cases} \sum_{s \in S} \lambda_s b_{sI} + \sum_{s \in S, f \in F} \bar{\lambda}_{sf} \bar{e}_{sfI} \text{ when } \pi_{sfi} - \lambda_s q_{sfi} - \bar{\lambda}_{sf} \leq 0, \forall s \in S, f \in F, i \in I \\ +\infty \text{ otherwise.} \end{cases} \end{aligned}$$

The optimal solution generates Lagrange multipliers (non-negative) for the grand coalition, λ_s $\forall s \in S$ and $\bar{\lambda}_{sf}$ $\forall s \in S, f \in F$, satisfying $v_I = \max_e L_I(\lambda, e)$. Otherwise, there are possibilities for aggregate improvements in resource allocation. The Lagrange multipliers, also called shadow prices, have an important interpretation and can be used to find core allocations for the grand fisheries coalition. The intuition behind this becomes clearer by considering the dual program

$$\begin{array}{lllll} \text{Minimize} & \sum_{s \in S} \lambda_s b_{sI} + \sum_{s \in S, f \in F} \bar{\lambda}_{sf} \bar{e}_{sfI} & & \\ \text{s.t.} & \pi_{sfi} - \lambda_s q_{sfi} - \bar{\lambda}_{sf} & \leq & 0, \ \forall s \in S, f \in F, i \in I \\ \text{and} & \lambda_s, \bar{\lambda}_{sf} & \geq & 0, \ \forall s \in S, f \in F. \end{array}$$

By imputing a value to each unit caught of species s and to each unit of harvesting capacity $\bar{e}_{sfi}$, the optimal dual solution produces shadow prices, λ_s and $\bar{\lambda}_{sf}$, that

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[6] The only circumstances that might justify absence of transaction costs in fisheries is that in which the agents have great deal of knowledge about each other and are involved in repeat bargaining [15]. Those circumstances can be found in tribal societies and other small communities. In such a world, transaction costs are very low because of a dense social network of interactions.

minimizes the alternative cost of all available resources, b_{si} and $\bar{e}_{sfi}$.

Theorem 1 (Shadow prices yield core solutions) *Suppose* λ_s *and* $\bar{\lambda}_{sf}$ *are shadow prices for the grand fisheries coalition* I. *Then the profit allocation*

$$u_i := \sum_{s\in S} \lambda_s b_{si} + \sum_{s\in S, f\in F} \bar{\lambda}_{sf} \bar{e}_{sfi}, \quad \forall i \in I \tag{2}$$

belongs to the core.

Proof. Let the Lagrangian L_C of coalition C,corresponding to problem (1), be defined like L_I with, of course, the modification that $\sum_{i\in C}$ replaces $\sum_{i\in I}$. Social stability prevails because C receives profit

$$\begin{aligned}\sum_{i\in C} u_i &= \sum_{i\in C, s\in S} \lambda_s b_{si} + \sum_{i\in C} \sum_{s\in S, f\in F} \bar{\lambda}_{sf} \bar{e}_{sfi} = \\ \max_e L_C(\lambda, e) &\geq \min_\lambda \max_e L_C(\lambda, e) \geq \max_e \min_\lambda L_C(\lambda, e) = v_C.\end{aligned}$$

The last inequality is often referred to as weak duality. Forming of the grand coalition I ensures strong duality. That is

$$v_I \geq \max_e L_I(\lambda, e) \geq \min_\lambda \max_e L_I(\lambda, e) \geq \max_e \min_\lambda L_I(\lambda, e) = v_{I.}$$

So Pareto efficiency does indeed prevail:

$$v_I = \sum_{i\in I} u_i = \sum_{i\in I, s\in S} \lambda_s b_{si} + \sum_{i\in I} \sum_{s\in S, f\in F} \bar{\lambda}_{sf} \bar{e}_{sfi} = \max_e L_I(\lambda, e). \quad \blacksquare$$

The core is in principle analogous to the Nash equilibrium from a non-cooperative game where an outcome is stable if no deviation is profitable. This result means that no agent i or strict subgroups $C \subset I$ can strictly improve its lot by going alone. Any agent gets its share of the total profit in accordance with its contribution to the fishery (collective) coordinated enterprise. In particular, agents that bring very scarce resources to the collectivity will be well compensated. However, the incentives for cooperation are explained by increased substitution possibilities alone. Economies economy of scale are absent here, each agent having a linear technology.

Implementation of core allocations in fisheries follows from theorem 1: If individual fishing quotas and harvesting capacity were traded at constant unit prices, λ_s and $\bar{\lambda}_{sf}$ respectively, then agent i receives $\sum_{s\in S} \lambda_s b_{si} + \sum_{s\in S, f\in F} \bar{\lambda}_{sf} \bar{e}_{sfi}$ from the cooperative. In principle, such arrangements decentralize both fishing activities and profit contributions.

3. An Example of Efficient Common Pool Fisheries

Exclusive owners of fishing quotas are often plagued with unfavourable conditions such as great distances to fishing grounds, lack of know-how or disharmony between resource situation and fleet composition. As such, they would have economic incentives to join a coalition with a better situated agent if introduced to a sharing rule as in (2). Following the procedure above we illustrate this by a numerical two-national and two-species example as displayed in Table 1.

Table 1. The operative environment for the two nations.

<table>
<tr><td><i>Non-cooperation</i></td><td>→</td><td><i>Cooperation</i></td></tr>
<tr><td>Quotas in tonnage (b_{si})
<table>
<tr><td>s\i</td><td>1</td><td>2</td></tr>
<tr><td>1</td><td>50</td><td>50</td></tr>
<tr><td>2</td><td>100</td><td>0</td></tr>
</table></td><td>→</td><td>$b_{sI} := \sum_{i=1}^{2} b_{si}, \forall s \in S$
$b_{1I} = 100, b_{2I} = 100$</td></tr>
<tr><td>Harvesting capacity ($\bar{e}_{sfi}$), as max. number of fishing trips
<table>
<tr><td>i</td><td colspan="2">Nation 1</td><td colspan="2">Nation 2</td></tr>
<tr><td>s\f</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>1</td><td>50</td><td>10</td><td>250</td><td>15</td></tr>
<tr><td>2</td><td>20</td><td>100</td><td>25</td><td>100</td></tr>
</table></td><td>→</td><td>$\bar{e}_{sfI} := \sum_{i=1}^{2} \bar{e}_{sfi}, \forall s \in S, f \in F$
$\bar{e}_{11I} = 300, \bar{e}_{12I} = 25$
$\bar{e}_{21I} = 45, \bar{e}_{22I} = 200$</td></tr>
<tr><td>Cost per fishing trip (c_{sfi})
<table>
<tr><td>i</td><td colspan="2">Nation 1</td><td colspan="2">Nation 2</td></tr>
<tr><td>s\f</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>1</td><td>5,000</td><td>2,000</td><td>6,000</td><td>1,500</td></tr>
<tr><td>2</td><td>800</td><td>500</td><td>1,000</td><td>200</td></tr>
</table></td><td>→</td><td>c_{sfi} = unchanged</td></tr>
<tr><td>Catch per fishing trip (q_{sfi})
<table>
<tr><td>i</td><td colspan="2">Nation 1</td><td colspan="2">Nation 2</td></tr>
<tr><td>s\f</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>1</td><td>500</td><td>2</td><td>100</td><td>4</td></tr>
<tr><td>2</td><td>6</td><td>20</td><td>8</td><td>40</td></tr>
</table></td><td>→</td><td>q_{sfi} = unchanged</td></tr>
<tr><td>Price (p_s)
$p_1 = 20, p_2 = 10$</td><td>→</td><td>p_s = unchanged</td></tr>
</table>

Operating with the information in table 1 contribution per fishing trip π_{sfi} becomes

i	Nation 1		Nation 2	
s\f	1	2	1	2
1	5,000	-1,960	-4,000	-1,420
2	-740	-300	-920	200

where total contribution from non-cooperative fisheries is as follows

$$v_1 = 250, \quad v_2 = 20, \quad \sum_{i=1}^{2} v_i = 270.$$

By establishing a two-national coalition where all resources are commonly used, the program in (1) now becomes

$$\begin{array}{llllllll}
\text{Maximize} & \pi_{111}e_{111} & +\pi_{112}e_{112} & +\pi_{121}e_{121} & +\pi_{122}e_{122} & & & \\
 & +\pi_{211}e_{211} & +\pi_{212}e_{212} & +\pi_{221}e_{221} & +\pi_{222}e_{222} & & & \\
\text{subject to} & q_{111}e_{111} & +q_{112}e_{112} & +q_{121}e_{121} & +q_{122}e_{122} & \leq & b_{1I} & \\
 & q_{211}e_{211} & +q_{212}e_{212} & +q_{221}e_{221} & +q_{222}e_{222} & \leq & b_{2I} & \\
 & e_{111} & +e_{112} & & & \leq & \bar{e}_{11I} & (3) \\
 & e_{211} & +e_{212} & & & \leq & \bar{e}_{21I} & \\
 & & & e_{121} & +e_{122} & \leq & \bar{e}_{12I} & \\
 & & & e_{221} & +e_{222} & \leq & \bar{e}_{22I} & \\
\text{and} & e_{111}, e_{112}, & e_{121}, e_{122}, & e_{211}, e_{212}, & e_{221}, e_{222} & \geq & 0 &
\end{array}$$

which demonstrates considerable gains compared to non-cooperative fisheries

$$\begin{array}{rcl}
1,040 & = & v_I > \sum_{i=1}^{2} v_i = 270; \\
e_{111} & = & 200, \ e_{112} = 0, \ e_{121} = 0, \ e_{122} = 0 \\
e_{211} & = & 0, \ e_{212} = 0, \ e_{221} = 0, \ e_{222} = 200.
\end{array}$$

The dual solution to (3)

$$\begin{array}{lllll}
\text{Minimize} & 100\lambda_1 + 200\lambda_2 + 300\bar{\lambda}_{11} + 45\bar{\lambda}_{21} & & & \\
 & +25\bar{\lambda}_{12} + 200\bar{\lambda}_{22} & & & \\
\text{subject to} & 500\lambda_1 + \bar{\lambda}_{11} & \geq & 5,000(\pi_{111}) & (a) \\
 & 100\lambda_1 + \bar{\lambda}_{11} & \geq & -4,000\,(\pi_{112}) & (b) \\
 & 2\lambda_1 + \bar{\lambda}_{12} & \geq & -1,960\,(\pi_{121}) & (c) \\
 & 4\lambda_1 + \bar{\lambda}_{12} & \geq & -1,420\,(\pi_{122}) & (d) \\
 & 6\lambda_2 + \bar{\lambda}_{21} & \geq & -740(\pi_{211}) & (e) \\
 & 8\lambda_2 + \bar{\lambda}_{21} & \geq & -920(\pi_{212}) & (f) \\
 & 20\lambda_2 + \bar{\lambda}_{22} & \geq & -300(\pi_{221}) & (g) \\
 & 40\lambda_2 + \bar{\lambda}_{22} & \geq & 200(\pi_{222}) & (h) \\
\text{and} & \lambda_1, \lambda_2, \bar{\lambda}_{11}, \bar{\lambda}_{21}, \bar{\lambda}_{12}, \bar{\lambda}_{22} & \geq & 0 &
\end{array}$$

generates the shadow prices for the fisheries cooperative

$$\lambda_1 = 10, \ \lambda_2 = 0, \ \bar{\lambda}_{11} = 0, \ \bar{\lambda}_{21} = 0, \ \bar{\lambda}_{12} = 0, \ \bar{\lambda}_{22} = 200.$$

The shadow prices shows that species 1 and the harvesting capacity $\bar{e}_{22I}$ are scarce, meaning that alternative costs are determined by those endowments. Since e_{111} is most efficient in relation to species 1, its alternative cost per unit catch becomes $\lambda_1 = \frac{\pi_{111}}{q_{111}} = \frac{5{,}000}{500} = 10$ as implied by restriction (a). Restriction (b) to (g) represents fishing activites that cannot match the alternative costs generated by more efficient harvesting technologies and their effort are thereby not demanded in the optimal solution. Since e_{222} is most efficient in relation to the use of $\bar{e}_{22I}$, its alternative cost per unit fishing effort becomes $\bar{\lambda}_{22} = \pi_{222} - q_{222}\lambda_2 = 200 - 40 \times 0 = 200$ as implied by restriction (h). That is, effort from this vessel group is demanded in the optimal solution.

Using the allocation rule in (2) we get the following profit allocation

$$\begin{aligned}
u_1 &= \lambda_1 b_{11} + \lambda_2 b_{21} + \bar{\lambda}_{11}\bar{e}_{111} + \bar{\lambda}_{21}\bar{e}_{211} + \bar{\lambda}_{12}\bar{e}_{121} + \bar{\lambda}_{22}\bar{e}_{221} \\
&= 520 > 250 = v_1 \\
u_2 &= \lambda_1 b_{12} + \lambda_2 b_{22} + \bar{\lambda}_{11}\bar{e}_{112} + \bar{\lambda}_{21}\bar{e}_{212} + \bar{\lambda}_{12}\bar{e}_{122} + \bar{\lambda}_{22}\bar{e}_{222} \\
&= 520 > 20 = v_2
\end{aligned}$$

and thereby a forming of the two-national coalition will take place.

4. Concluding Remarks

Exclusive resource management (economic zones, individual fishing quotas etc.) often yield allocation policies where substitution possibilities are overlooked. By introducing an allocation rule that complies with the core concept to heterogeneous fisheries we have shown how agents facing such conditions may achieve greater efficiency and full use of substitution possibilities when their endowments are managed as a common pool resource (CPR). This is done by using an optimization program that allow variation in objectives and technologies/skills across agents facing joint use of quotas and capacities. The associated shadow prices define a payment scheme (a contract) that provides all potential contributors with sufficient incentives to participate. Implementation may come about via a competitive market where quotas and harvesting capacities are traded at the optimal shadow prices. In such a setting it may well happen that some party who owns no quota, undertakes much harvesting: Any inefficient fisherman can transfer his quotas to owner(s) of more efficient harvesting capacity. As compensation it receive side payments that at least matches foregone income.

As a general conclusion, we can state that efficient fisheries cannot be guaranteed unless harvesting rights belongs to all potential contributors to core solutions, quota owners or not. The results reconcile with plentiful observations from tribal communities where sustainability is secured through successful sharing of fishing grounds, food, services and skills.

The core allocation mechanism presented here contradicts the standpoint taken by traditional resource economic theory where shared use of resources inevitably are linked to the tragedy of the commons and emptiness of the core, e.g. [2], [14]. This pessimism towards common property regimes is explained by a total absence of cooperative incentives in the resource economic approach. Since successful sharing rules through history have been at the heart of human-environmental activities [16], the position of property theorists seems rather precarious.

All this said, we have to have in mind that common property institutions are not likely to evolve unless the appropriators are facing a resource that is both scarce and of crucial importance for their existence [16]. The appropriators ability to communicate efficiently is another important criteria. Thus it is not surprising that the appearance of CPR institutions in fisheries so far have been restricted to isolated small-scale communities. First, it was not until recently that national governments started to realize that the resources of the ocean are exhaustible. Second, the ocean represents a large scale CPR dilemma where communication opportunities for all parties have been highly limited. Third, socio-ecological knowledge about CPR institutions is often dependent on cultural setting and thereby not easy to pass on to the scientific community or (and) policy makers. That the international fishery community have chosen individual property rights regimes above common property regimes is thus a consequence of conditions that have been close to Prisoners' Dilemma type of setting.

Privatization of the ocean have given nations and individuals access to more controllable resources and thereby valuable experience and knowledge about resource management. As such it can be seen as an important (learning) step towards more sustainable fisheries. We are about to learn that the ocean is a common pool resource in its totality and that successful fisheries often requires non-exclusive - and coordinated - harvesting policies. Increased awareness about the vulnerability of marine ecosystems to harvesting and great improvements in communication skills has brought the global fishery community closer to the conditions shared by small-scale common property communities. The applicability of core allocations in fisheries should therefore not be restricted to tribal communities in the future.

Institutional design is beyond the scope of this study. It is, however, important to be aware of the fact that implementation of core allocations in fisheries requires institutions that secure a symmetric information flow, a credible controlling mechanism and a suitable transaction environment. To address institutions and transaction costs seem an important extension.

The analysis may also be extended to involve uncertainty by introducing multi-stage stochastic programming, e.g. [3], [10], [19] and non-linearity [19] with a great variety of applications that may sustain non-exclusive resource use.

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