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Effort optimisation in artisanal fisheries with multiple management objectives, collective quotas and heterogeneous fleets*

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In this study, we analyse effort optimisation in common rights-based joint-stock artisanal fisheries when several objectives are pursued by the authorities and the fleets are heterogeneous. The purpose is to discuss policy options available to the authorities and their implications in terms of trade-offs between goals. We apply a multi-objective programming model to the sardine and anchovy artisanal fisheries in central southern Chile. The results suggest that the regulatory system generates inefficient solutions for profit and employment maximisation goals. Moreover, the fleet structure of the artisanal organisations is central for the outcomes obtained by different policy simulations. To improve effort assignment, the authorities should seek to increase flexibility in the system.

Key words: artisanal fisheries, collective quotas, effort optimisation, multi-objective.

1. Introduction

In this study, we analyse effort optimisation in collective rights-based joint-stock fisheries when the authorities are pursuing several objectives and the fleets are heterogeneous. The purpose is to discuss policy options available to the authorities and their implications in terms of trade-offs between goals. We apply a multi-objective programming model to the sardine and anchovy artisanal fisheries in central southern Chile. The results suggest that the regulatory system generates inefficient solutions for profit and employment maximisation goals. Moreover, the fleet structure of the artisanal organisations is central for the obtained outcomes of different policy simulations. To improve effort assignment, the authorities should seek to increase flexibility in the system.

Several analyses of fishery management options with multiple objectives can be found in the literature. A tool used to deal with distinct and conflicting goals has been multi-objective optimisation (see Drynan and Sandiford 1985; Dupont and Phipps 1991; Placenti *et al*. 1992; Gilbert and Enriquez 1994;

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Padilla and Copes 1994; Leung *et al.* 2001). In contrast, the analyses of collective rights-based fisheries, although growing in number, are still scanty (Berkes 1989; Pinkerton 1989). Their properties in terms of efficiency and other policy goals are not well understood (Baland and Platteau 2003). An important difference that emerges when comparing individual rights systems to collective rights systems is that the latter has heterogeneity within each organisation, including different technical efficiencies. On the other hand, the collective nature of the rights induces more horizontal effort assignment criteria than an assignment based on purely efficiency considerations. Thus, there is a certain tension between equity and efficiency within the organisation. Finally, collective rights systems normally limit the trade of fishing rights between organisations, which adds additional rigidity to the system.

For the authorities, the problem of assigning collective quotas is related to the expected outcomes of this system, in terms of the objectives of fishery management policies. In particular, different types of organisations may have different fleet structures and dissimilar criteria when internally assigning their quota. Therefore, they may generate different outcomes in terms of efficiency, equity, employment, or other objectives that the authority may have. There is plenty of evidence, based on various methodologies, indicating that different agents assign diverse priorities to different objectives (see e.g. Soma 2003; Adrianto *et al.* 2005; Wattage *et al.* 2005; Himes 2007).[1] From a policy point of view, it is important to have clarity about the consequences of different quota assignments in diverse organisations to channel or induce an optimal assignment. For instance, the authorities could implement subsidies to induce the use of specific types of vessels within the organisations to attain a certain policy goal. Thus, with collective rights there is, at least, one additional dimension to take into consideration in the policy design, namely the optimal quota assignment for different types of organisations.

The Chilean authorities have regulated some artisanal fisheries with a collective quota system called Artisanal Extractive Regime. This regime allows the allocation of fishing quotas to artisanal organisations. The most important fisheries where this system has been applied are the sardine (*Strangomera bentincki*) and anchovy (*Engraulis ringens*) fisheries in central southern Chile, which is a joint-stock fishery.

Initially, when the system was launched in 2004, some fishermen distrusted the system or did not have enough information about it and did not create organisations that enabled them to obtain a quota. However, since then, they have become aware of the importance of having an organisation to secure a fishing quota and have increasingly entered the system. This has led to the increase in the number and change in participation of the total allowable quotas (TAQ) of different types of organisations. Moreover, individual fishermen have moved between different organisations. The development of the system

[1] In Chile there is also some evidence of specific objective priorities among artisanal fishermen obtained by hierarchical analysis. See Hernández and Quiñones (2010).

has also led to dissatisfaction with the obtained individual quotas and, therefore, to claims for higher total allowable quotas (TAQ) over the years (S. Schuermann, pers. comm., 2009). In this context, it is easy to imagine the great struggle for quotas that has originated during the implementation period of this collective rights-based system, with new fishermen asking for recognition of fishing histories all the time, constant requests for new organisation formation, members moving between organisations, etc. This has put pressure on the National Fisheries Council to increase the TAQ for sardine and anchovies. Higher quotas have been encouraged as a means to secure high employment levels and better living conditions for the fishermen (Leal *et al*. 2010). However, the properties of this system in terms of the objectives of fishery management in Chile are not known. Specifically, the outcomes of this system in terms of basic management goals, such as conservation, efficiency, employment creation and equity, have not yet been addressed in the literature.

In this study, we develop a multi-objective analysis of collective rights-based fisheries in central southern Chile to establish the implications of different quota assignments, in different types of fishery organisations, for the objectives of fisheries' management policies. Specifically, we are interested in evaluating how changes in the TAQ and a redistribution of the TAQ among different organisation types can affect the optimal solutions to obtain maximum profits (MAXP) and maximum employment (MAXE) in these fisheries.

In the following, we present the basic facts about the relevant fisheries and the management regime. Then, we present the model used for the estimations and the data. Thereafter, we show the results and we end with the conclusions followed by an Appendix.

2. Basic facts and administration regime of the sardine and anchovy artisanal fisheries in central southern Chile

The artisanal fleet analysed in this study operates on the Chilean sardine (*S. bentincki*) and anchovy (*E. ringens*). These species are primarily located from the Chilean coastline to approximately 30 km west and between 33°3′ and 44°3′ south latitude. These species are often found in mixed stocks, and the available fishing methods are not capable of extracting them separately (Subsecretaria de Pesca 2008a,b). The artisanal fleet is heterogeneous and composed of small boats and vessels < 18 m in length, with a 80 m^3 hold capacity and 50 gross register tonnages. However, they share the total allowable catch for these species with the larger industrial fleet. The industrial fleet, according to Chilean law, may not operate within the first 10 km of the coast. This strip is reserved exclusively for the operation of the artisanal fleet.

Sardine and anchovy fishing occurs principally in the BíoBío Region (south of Santiago de Chile). In 2008, more than 485,000 tonnes of sardines and more than 163,000 tonnes of anchovies were landed in this region; of these, 85 and 41 per cent, respectively, were landed by the artisanal fleet (Servicio

Nacional de Pesca, 2008). It is estimated that these artisanal fisheries can employ up to 3900 crewmembers (Castillo 2010). The landed fish is used primarily to produce fishmeal that is later exported or used as input in the domestic salmon aquaculture industry.

The sardine and anchovy fisheries are regulated by the Chilean authorities in accordance with the General Law of Fisheries and Aquaculture (LGPA 1991). This law establishes that these fisheries are considered to be in a state of 'Full Exploitation' and, therefore, are to be administered with a total allowable quota, TAQ, that is partitioned between industrial and artisanal fishers. The industrial fraction of the TAQ is regulated by an individual quota system with limited transferability (Chávez *et al.* 2004). The artisanal fraction of the TAQ is regulated by the Artisanal Extractive Regime (RAE in its Spanish acronym). This regime allocates fishing quotas to artisanal fishers through different methods. However, until now, the artisanal fraction of the TAQ has been distributed by regions and by fishing areas, and within these fishing areas by fishermen organisations (Subsecretaria de Pesca 2004). The basic quota assignment criterion has been the organisation's 'real history of landings'. To make this criterion operational, several aspects have been considered, such as the number of registered vessels for each organisation; seniority of the vessel owners; environmental and oceanographic phenomena that has affected the fisheries; and the fishing rate of vessel owners. Basically, what the authorities have tried to do is to allocate fishing quotas to each organisation according to the fishing history of each of the vessel owners that belongs to the organisation. But, it is important to notice that the quotas are assigned to the organisation and not to the individual vessel owners. In this sense, it is a system of collective fishing rights.

The distribution of the fishing quotas, within the organisation, is something to be decided by the members of each organisation. The organisation must agree on a *Catch Administration Programme*, which specifies how the organisation quota will be divided between the organisation's members. This programme is supervised by the National Fisheries Service (SERNAPESCA in its Spanish acronym). Registered vessel owners that do not belong to an organisation but have a real history of landings in these fisheries are allowed to fish on a residual quota. In this case, for this quota, the system works as an *Olympic race fishery;* that is, any of the fishermen allowed to participate in this quota may catch fish until the quota is exhausted.[2] Finally, fishing seasons also regulate these fisheries.

In the BíoBío Region in 2009, there were 51 artisanal fishermen organisations in the sardine and anchovy fisheries. However, the number of organisations has grown over time, as the fishermen have become aware of the

[2] This system is similar to that used in the U.K., where quota is allocated to producer organizations and non-affiliated producers (see Hatcher *et al.* 2002). However, the Chilean system is more rigid in the sense that membership in organizations that do not belong to the vessel's fishing area are not allowed.

advantages of belonging to an organisation for securing a fishing quota. In the year 2006, only 21 organisations were registered in the sardine and anchovy fisheries of the BíoBío Region. Thus, the number of organisations increased by 30 units between 2006 and 2009. The basic unit of analysis is the organisation. However, to make the interpretation of the results manageable, we have grouped the organisations in five different organisation types (see Barriga *et al*. 2009). In our view, the organisations that belong to each type are sufficiently homogenous within each category and different between categories to make the analysis useful. Moreover, the importance of the different types of organisations has changed over time. As it can be seen in Figure 1, in 2006, the predominant types of organisations were guilds and trade unions, with roughly equal importance. By the year 2009, two other types of organisations had emerged: the communities and the cooperatives. Moreover, the trade unions had grown in absolute and relative importance in the total number of organisations.

Moreover, if we consider the quota distribution between different types of artisanal organisations, we can see in Figure 2 that in the year 2006 more than 88 per cent of the artisanal fishing quota went to the guilds. In 2009, this share was reduced primarily in favour of the trade unions. The other categories had a small proportion of the total quota. Specifically, the residual category has had a very small proportion of the TAQ because this system was implemented, suggesting why so many fishermen have been interested in leaving this quota and forming an organisation to obtain a share in accordance with their fishing histories.

Finally, as we can see in Figure 3, the composition of the fleet, in terms of vessel size, differs between different types of organisations. While the trade unions and guilds have higher proportions of large vessels, the fishermen that operate in the residual quota, or those that belong to the community organisations, tend to have a higher proportion of small boats. This is important because the reassignment of quota among organisations as a result of differing fleet compositions in different organisation types will have diverse effects on the total effort and policy objectives, such as profits and employment.

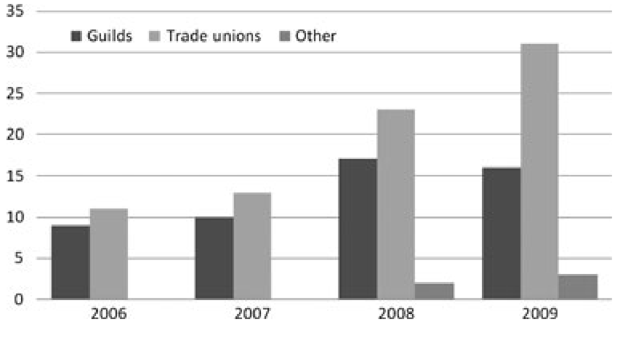


Figure 1 Number of organisations by type in the artisanal sardine and anchovy fisheries in the BíoBío Region, Chile. Several years. The category other includes communities and cooperatives. Source: Servicio Nacional de Pesca, Chilean Government.

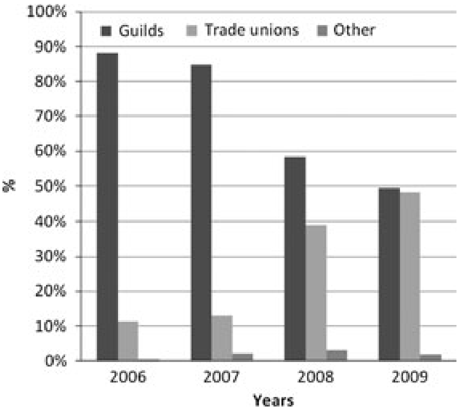


Figure 2 Distribution of total catch quota by type of organisation in the artisanal sardine and anchovy fisheries in the BíoBío Region, Chile. Several years (percentages). The category other includes communities and cooperatives and residual fishermen. Source: Servicio Nacional de Pesca, Chilean Government.

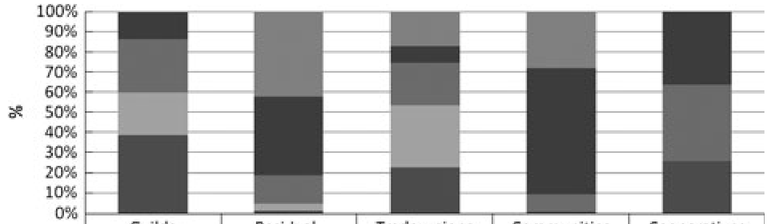
3. Methods and data

We used a multicriteria programming technique to analyse how the assignment of the artisanal fraction of the sardine and anchovy TAQ in the BíoBío Region (through the RAE) affects fishing policy objectives. This type of approach has been used previously to analyse multiple objectives in fishery management (see e.g. Mardle and Pascoe 1999; Leung 2006). It has the advantage of handling several objectives and restrictions simultaneously. If there are trade-offs between the objectives, then the solution to the assignment problem is not a single point, but an area or a number of points, depending on the importance given to the different objectives. In this case, we have adapted a model, proposed by Padilla and Copes (1994), to the sardine and anchovy artisanal fisheries of the BíoBío Region.

The four fishery management objectives considered are the following: the maximisation of economic benefits (efficiency), employment maximisation, the preservation of fish stocks (conservation) and fair quota assignment (income distribution). These are objectives to be considered in the Chilean fisheries' management policy (Subsecretaria de Pesca 2007).[3] To include these objectives in the analysis, the first two are explicitly modelled as maximands and the second two as restrictions to the maximisation problem. Thus, we can model our problem as a bi-criteria programming model. Moreover, in this model, we identified only one control variable, *f,* which is the fishing effort.

The explicit objectives in the bi-criteria programming model can be expressed as:

[3] In the case of the sardine and anchovy fisheries, the employment maximization objective can be seen as a result of the National Fisheries Council's attempt to meet conflicting demands for higher quotas among artisanal fishermen.



	Guilds	Residual	Trade unions	Communities	Cooperatives
BRV	1%	47%	41%	9%	0%
BMO	14%	43%	20%	20%	2%
<12	29%	16%	50%	3%	3%
12–<15	24%	4%	73%	0%	0%
15–18	42%	1%	54%	0%	2%

Figure 3 Composition of the fleet by vessel size according to type of organisation in the artisanal sardine and anchovy fisheries in the BíoBío Region, Chile. Year 2009 (percentages of total). BRV, rowboat; BMO, motor boat; <12, vessels <12 m long; $12–<15$, vessels between 12 and 15 m long; 15–18, vessels between 15 and 18 m long. Source: Servicio Nacional de Pesca, Chilean Government.

$$Max h_1(f) = \sum_i \sum_j \sum_n p_i q_{ijn} f_{jn} - \sum_j \sum_n c_{jn} f_{jn}, \tag{1}$$

$$Max h_2(f) = \sum_n \sum_j l_{jn} f_{jn}. \tag{2}$$

Equation (1) specifies the maximisation of benefits from artisanal fishing, where i represents the fish species; j represents the type of vessel (size); and n represents the type of organisation. The rest of the notation is as follows: p_i are the fish prices for the ith species, q_{ijn} is the catchability coefficient associated with the ith species, jth type of vessel and n type of organisation; f_{jn}, is the fishing effort measured as number of trip days for vessel type j and organisation type n; c_{jn} is the trip cost standardised by effort for vessel type j and organisation type n.

Equation (2) specifies the maximisation of fisheries employment, as another target of the Chilean fishery authorities, where l_{jn} is the labour requirement per vessel, measured as number of man-days standardised by effort for type of vessel j and organisation type n.

We added three sets of restrictions to the maximisation problem, which are the following:

$$\sum_i \sum_j \sum_n q_{ijn} f_{jn} \leq Y, \tag{3}$$

$$\frac{\sum_i^I \sum_j^J q_{jn} f_{jn}}{\sum_i^I \sum_j^J q_{jm} f_{jm}} = \frac{Q_n}{Q_m} = CR_{nm}, \tag{4}$$

for n, m = 1, …, N

$$f_{jn} \leq \max(f^{*}). \tag{5}$$

Equation (3) represents the conservation objective as a restriction. Total catch of both species should be less or equal to the total allowable catch, Y. Total catch is the sum of all landings from both species generated by the artisanal fleet.[4]

Equation (4) introduces an equity restriction.[5] In this sense, it includes the quota distribution objective as a restriction in the maximisation problem. This restriction indicates that the ratio of the total landings of two organisations, n and m, should equal an exogenously given constant, CR. Given that each organisation uses its quota completely, this constant should reflect the effect of the distributional criteria used to assign quota to each organisation.[6] Basically, we consider the distribution of quota between organisations, and organisation types, as exogenous to the authority's decision. Therefore, we have chosen to model it as a constraint to the maximisation problem.

Equation (5) is a restriction to prevent the optimisation process from giving a solution that exceeds what is technically possible, namely that the number of trips performed by the vessel type, within an organisation, surpasses the maximum feasible level of effort, f^*, within the sample period.[7]

Thus, the complete problem for the planner is to simultaneously maximise the two objective functions (Eqns 1,2) subject to three restrictions (Eqns 3–5) with respect to fishing effort (f_{jn}). In this setting, prices (p_i), trip costs per effort unit (c_{jn}), catchability (q_{ijn}) and labour requirements per effort unit (l_{jn}) are considered exogenously determined. Moreover, the total allowable catch (Y_i), the organisations share of the artisanal quota (CR_{nm}) and the maximum effort (f^*) restrictions are also exogenous to the maximisation decisions of the planner in the short run.

The idea of a central planner that adjusts fishing efforts is, of course, an analytical aid device to determine the solution to the assignment problem, when the objectives of profits and/or employment maximisation are pursued by the individual organisations.

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[4] The sardine and anchovy TAQ are set separately. However, these are fisheries with joint stocks and it is not possible to discriminate between the species in terms of catch. Therefore, in practice, the authorities allow individual organizations to substitute one species for another when one's quota is exhausted and the other's is not. This means that, in practice, the authorities set an aggregate joint quota for both species, and not each quota separately.

[5] A similar relation, designated as 'relative stability', was used by Pascoe and Mardle (2001) to hold the resource distribution between U.K. and France. However, they included the relation as an objective in the maximized function, instead of a restriction, as we do.

[6] The quota assigned to each organization will be equal to the sum of the individual quotas entitled by each individual vessel owner, which in turn are determined primarily by their historical catch records. Thus, the individual vessel owners determine the organization quota when they choose to enter the organization.

[7] In these fisheries, a trip typically takes one day. Controlling for fishing seasons, the maximum number of days (trips) a vessel can perform a year is 270. This is also regulated by the authorities that have explicitly ruled this maximum figure (see Subsecretaria de Pesca 2009).

It should be clear that the results obtained from this model depend on a correct specification of the objectives in the model. There is a plethora of potential management objectives in the literature and the authorities' stated objectives do not necessarily correspond with the actual goals (see e.g. Beddington & Rettig, 1984). Omitting an objective in the problem formulation could lead to a different optimal effort assignment.

The main difference between this model and the one used by Padilla and Copes (1994) is that these authors are interested in modelling different types of gear for homogeneous sectors, while in this study, the fleets of the different organisations are heterogeneous.

The calibration of the model was performed with average information for the sardine and anchovy fisheries in the BíoBío Region for the year 2009. Catchability (q_{ijn}), and labour requirements (l_{jn}) were calculated from the National Fisheries Services' databases. Prices (p_i), were constructed from Central Bank statistics on export prices.[8] Trip costs (c_{jn}) were calculated from FIP (2006). The total available catch (Y) and the organisations' share of the artisanal quota (CR_{nm}) were obtained from official sources (Subsecretaria de Pesca 2009). The maximum (f^*) effort restriction was calculated as the maximum legal number of fishing days per vessel. A more detailed account of how the basic model parameters were constructed is given in the Appendix.

The number of restrictions in the model was 33: one for the total allowable catch, 10 for the equity restrictions between organisations and 22 for the maximum effort restrictions for each vessel category in each organisation.[9]

The solution of this model is not unique. There is a *trade-off* between the profit and the employment objectives. Thus, the optimisation of this model gives a frontier of Pareto solutions for the objective functions (Mardle and Pascoe 1999). We used a graphical representation of this frontier. The decision maker can choose, according to his or her preferences or priorities, a specific solution within the area delimited by this frontier. We used this solution to evaluate the actual effort distribution and discuss changes to increase profits and employment. Once the feasible area was estimated, we used the model to calculate how marginal changes in the restrictions affect the optimal solutions. Specifically, we evaluated how marginal changes in the total quota for each species, and a change in the distribution of the quota among different types of organisations, affect the optimum level of profits and employment.

To obtain the solution, we used an optimisation method called restrictions generating technique (see Willis and Perlack 1980; Enríquez-Andrade and Vaca-Rodríguez 2004), which was implemented with LINGO 6 software.

[8] To the best of our knowledge, no significant differences in fish prices obtained by different groups of artisanal fishermen should exist.

[9] There are five organization types and five vessel categories, which amount to 25 restrictions. However, in three organization types one vessel category did not exist.

4. Results

To characterise the trade-off between the profit and employment objectives, we chose three different reference points: MAXP (A), where profits are maximal; MAXE (C) where employment is highest; and INTER (B) an intermediate point in the Pareto front between these two extreme points. This last point was determined as that corresponding to a kink in the Pareto front.

In Figure 4, we can see these points depicted on the Pareto front and how different solutions are obtained according to the weights given to each objective. Profits, in the abscissa, are measured in millions of CLP,[10] while employment is measured in thousands of man-days on the ordinate axis. We have also depicted in the figure the actual outcome of the fisheries in 2009.

The Pareto frontier has two distinct kink points that generate three segments: one at a high employment – medium profit level and the other at a low employment – high profit level. This means that the trade-off has different exchange rates along the Pareto frontier. In the first segment, the rate of exchange between employment and profits is low, suggesting that with relatively small employment losses it is possible to improve profits substantially. In the last segment, the rate is high, meaning that high employment losses would generate small profit increases. This information is undoubtedly important for a policy that aims to reconcile high profits (high fisher income) with high employment.

Moreover, the actual distribution of employment and profits is, as expected, below the frontier. However, it seems that the distance to the optimal values of employment are higher than that to the optimal values of profits: the largest difference between actual profits and MAXP along the Pareto frontier is 2.1 percent, while the equivalent difference in employment is

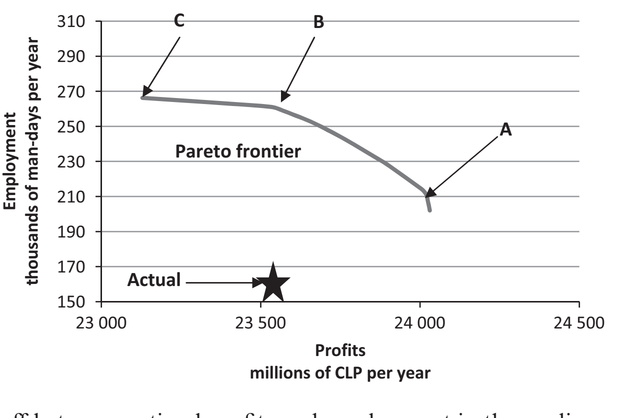

Figure 4 Trade-off between optimal profits and employment in the sardine and anchovy artisanal fisheries in central southern Chile. The star in the figure indicates the actual distribution of employment and profits. Source: Estimations based on Servicio Nacional de Pesca, Chilean Government.

[10] One million CLP (Chilean pesos) was approximately 2000 US$ in 2009.

66.3 per cent. This result suggests that organisations most likely aim for a greater profit margin than for employment maximisation. Thus, a potential intervention by the authorities, to affect effort distribution, has more to gain in terms of employment than in terms of profits.

The specific values for the reference points, and the differences of these points from actual values, are given in Table 1. Moreover, in this table, we have also calculated the total number of vessels and the total number of fishermen active in these optimal points. The total number of vessels was calculated as the sum of all those vessels that, according to the solution, had at least one trip, and the total number of active fishermen as the sum of all the crew members that corresponded to those vessels.

The variation in profits and employment between the MAXE and MAXP is −4 per cent and +32 per cent, respectively. This variation is relatively small in profits, but large in employment. Profits will vary along the Pareto frontier by 902 million CLP, while employment will vary by 64,000 man-days. Thus, the average trade-off between employment and profits, for the whole frontier, is 71 man-days per million of CLP. However, for the first segment of the frontier, the trade-off is 970 man-days per million CLP, while for the last segment, it is only 12 man-days per million CLP. Moreover, profits will be reduced at the MAXE point, compared with actual values but will increase at the MAXP point. Employment, in turn, will increase at all three reference points, in comparison with the actual values. In concordance with this, optimisation implies that the total number of vessels operating, and thus, the total number of fishermen is reduced at all optimal points in comparison with the actual values. However, as the total number of man-days increases, this means that the catch is carried out with fewer, but more intensively used, vessels. Moreover, the vessels which are most apt for each objective would be used to their full capacity in order to attain the optimal solution. Thus, the difference between the optimal and actual values may reflect an organisation's use of criteria other than employment or profit maximisation criteria to assign fishing quota. For example, assigning quota in relation to a vessel's past fishing history or by equity considerations within the organisations, independent of the vessel's efficiency at attaining certain goals, might explain a suboptimal solution.

We will now consider the results disaggregated by organisation type and vessel category. In Table 2, we show the estimated aggregate effort, measured in trip days, by organisation type and by vessel category for the three reference points on the Pareto frontier and the actual effort levels.

As it can be seen in the totals, actual efforts are less than estimated optimal efforts at the three reference points for all organisation types, except the residual category. Thus, a move towards a more efficient assignment should increase the total effort exerted by the artisanal fleet. This result suggests that the quota assignment criteria used is not efficient whether the objective is to maximise profits or employment. Moreover, the results disaggregated by type of organisation imply that guild and cooperative organisations are profit

Table 1 Estimated optimal profits and employment at reference points for the sardine and anchovy artisanal fisheries in central southern Chile

Variables	Reference points at the pareto frontier			Actual values	Difference to actual values		
	Maximum profits (A)	Intermediate (B)	Maximum employment (C)		Maximum profits (A)	Intermediate (B)	Maximum employment (C)
Profits (millions of CLP)	24,031	23,533	23,129	23,536	495	−3	−407
Employment (thousand man-days)	202	261	266	160	42	101	106
No. of vessels	364	468	489	569	−205	−101	−80
No. of fishermen	3226	3556	3588	3787	−561	−231	−199

Source: Estimations based on Servicio Nacional de Pesca, Chilean Government.

Table 2 Estimated optimal effort at reference points by organisation type and vessel category in the sardine and anchovy artisanal fisheries in central southern Chile

Type	Organisation	Optimal efforts (days per year) Maximum profits	Intermediate	Maximum employment	Actual effort
1	Guild	9401	12,001	17,442	8241
2	Residual	254	1607	1936	791
3	Trade unions	14,025	30,115	30,115	8616
4	Community	1085	2191	2190	312
5	Cooperative	270	1511	1511	257
	Totals	25,037	47,425	53,196	18,217
Type	**Vessel**				
1	Rowboat	0	5339	5716	159
2	Motorboat	815	11,101	17,310	1181
3	Vessel < 12 m	270	8370	8370	1152
4	Vessel 12–< 15 m	13,484	13,279	13,230	1970
5	Vessel 15–18 m	10,467	9337	8568	13,755
	Totals	25,037	47,425	53,196	18,217

Source: Estimations based on Servicio Nacional de Pesca, Chilean Government.

oriented, that the fishermen operating in the residual quota could be in an intermediate position and that trade unions and community organisations are well below an optimal assignment. Finally, the basic problem with the actual distribution of effort between vessel categories seems to be that the proportion of effort assigned to the larger vessels (between 15 and 18 m) is too high and that assigned to the intermediate vessels (between 12 and 15 m) is too low. If one aims to maximise either profits or employment and could freely redistribute effort at will, then effort should be reduced in all other categories and be assigned to this intermediate vessel category.

To evaluate how the optimal solution varies in relation to different changes in the system's restrictions, we developed two simulations. First, we considered what would happen if the total artisanal available quota (TAQ) increased by 1000 tonnes. This exercise is important to evaluate if the profits and/or employment conditions for the artisanal fishermen would be significantly altered with this marginal change. From a practical point of view, this type of exercise shows the real gains that the release of 'extra-quotas' could have on the well-being of the fishermen population in these fisheries.[11] Second, we simulated what would happen if there were a redistribution of the TAQ among different organisations types. In this case, we held the TAQ constant, but redistributed it from four of the organisation types to the one remaining, in proportion to their base shares of the TAQ. That is, we withdrew a fraction of the 1000 tonnes to each of the other organisation types according to their

[11] It is not uncommon that Chilean fishery authorities give 'extra quotas' to fishermen groups after they apply pressure on the authorities.

initial shares of the TAQ, and, then, we transferred all these fractions, which sum up to 1000 tonnes, to the favoured organisation type. We repeated this exercise for each organisation type. This is equivalent to taking some of the quota assigned to certain organisations and giving it to other organisations. This can be seen as an evaluation of what has actually been happening in recent years in these fisheries, with the observed change in different organisations' shares of the TAQ. It is also an exercise of what would happen if the authorities chose to reassign the TAQ with an allocation formula that favoured certain types of organisations. The quota reassigned in this way was 1000 tonnes. This exercise was carried out for each organisation type.

The result of the first simulation, of a marginal increase in TAQ, is presented in Table 3. This table shows the results for maximum profits and employment evaluated at the MAXE and MAXP points.

As it can be seen, the change in optimal employment and profits are relatively small at both points. Employment increases between 207 and 210 man-days, which for a vessel between 15 and 18 m long means 21 days (or trips) of employment. Profits increase by 32,000,000 pesos, which amounts to a 0.14 per cent increase in actual profits. Therefore, this type of change has a relatively small impact on the total wellbeing of the artisanal fishermen. Thus, if the health of the fish stocks is at stake, it does not seem that increases in the TAQ have a good payoff in terms of profits or employment.

The result of the second simulation, of a redistribution of the TAQ between different organisation types, is presented in Table 4. This table shows the results for aggregated maximum profits and employment evaluated at the MAXE and MAXP points when the TAQ is redistributed, in 1000 tonnes, to each organisation type.

The results obtained are qualitatively the same between the two reference points. However, the estimated magnitude of the result is different between reference points. Total employment increases at both reference points when the quota reassignment goes to community organisations and to the residual quota, while it decreases when the reassignment goes to guild, trade unions and cooperative organisations. However, the employment gains are substantial in the first cases, while the losses are minimal in the second cases. In contrast, total profits increase at both reference points when the reassignment

Table 3 Simulated impact of an increase of 1000 tonnes in the sardine and anchovy TAQ in the artisanal fisheries in central southern Chile

	Absolute change	Percentage change
Maximum profits		
Change in profits (millions of CLP)	32.3	0.13
Change in total employment (man-days)	207.0	0.10
Maximum employment		
Change in profits (millions of CLP)	32.2	0.14
Change in total employment (man-days)	210.0	0.08

Source: Estimations based on Servicio Nacional de Pesca, Chilean Government.

Table 4 Simulated impact of a reassignment in the TAQ of 1000 tonnes by organisation type in the sardine and anchovy artisanal fisheries in central southern Chile

	Type of organisation				
	Guilds	Residual	Trade unions	Communities	Cooperatives
Maximum profits point					
Change in total profits (millions of CLP)	58.8	−1.0	0.02	−11.1	0.19
Change in total employment (No. of man days)	−7	412	−6	1493	−8
Maximum employment point					
Change in total profits (millions of CLP)	0.12	−16.7	0.08	−11	0.3
Change in total employment (No. of man days)	−10	1185	−9	1490	−12

Source: Estimations based on Servicio Nacional de Pesca, Chilean Government.

goes to guild, trade unions, and cooperative organisations and decrease when it goes to community organisations and residual fishermen, in both reference points. However, in general, the effect of this quota redistribution on MAXP is small in all cases because we have a relatively flat profit function. Therefore, these results reaffirm that when redistributing quotas among organisations, there is more to gain in terms of employment than profits. This result leads us to infer that profits and employment in the analysed fisheries have not been greatly affected by the fact that trade unions have increased their sharing of total catch in the last few years.

5. Summary and conclusions

In this study, we applied a multi-objective optimisation model to the analysis of collective fishing rights assignments to artisanal organisations in the pelagic fisheries of sardine and anchovies in central southern Chile. This assignment is carried out according to the historical fishing records of the vessel owners that are members of the organisations. However, the properties of this system, in terms of management goals, are unknown. Moreover, there have been drastic changes in the composition of the types of organisations that participate in these fisheries in the past years, which raise questions about how these changes might have affected the ability to attain efficient outcomes.

The results show that, with a reassignment of effort within the organisations, there is room for improving objectives such as profit maximisation and employment maximisation, without affecting conservation or actual distribution of quotas. This is most likely a result of the criteria used to assign fishing quotas to organisations and the internal criteria used by the organisations to assign their collective quota. Thus, the historical assignment formula does not seem to guarantee efficiency in attaining the management objectives.

However, the outcome is closer to profit maximisation than employment maximisation. With the actual fleet composition of the organisations much more employment, measured as man-days, could be generated, but this does not seem to be a priority for the organisations. It's important to consider that even if the organisation follows a consistent profit maximisation strategy, it should still be possible with an efficient use of vessels to increase total employment if this were a priority for society. The inefficiency of the actual assignment could be due to the criteria used to internally assign the collective quota, which prevents the use of more efficient vessels from generating surplus or employment. In particular, the inclusion of more flexibility in the regulatory system, to allow reassignment of quotas among organisations types, could help to improve the efficiency in the distribution of total effort.

The results also show that the trade-off between profits and employment is nonlinear. Therefore, the gains and losses of one objective in terms of another will depend on the fisheries' specific position along the Pareto frontier. However, in general, optimal profits seem to be rather unaffected by changes in employment, so there is room for developing employment policies with minimal profit losses, if this is a goal for the authorities.

Changes in the TAQ have minor effects on both optimal profits and employment. However, a redistribution of the TAQ among different types of organisations can have, depending on which organisation type is favoured, an important effect on employment. The fleet composition of the different organisations explains this result.

In terms of policy design, these results suggest that if the authorities aim to increase efficiency with collective fishing rights, they could promote trade within and among organisations. However, this might be politically and culturally difficult to implement with the artisanal fishermen. An alternative is to promote technological development of the artisanal fleet. Many of the results detected rely on the use of inadequate vessels to catch the quota within and among the organisations. In the light of the imperfections that the capital markets present, it may be justified, from a welfare point of view, that the authorities intervene to encourage vessel renovation. Finally, one should be cautious when using the obtained results, because these depend on a proper specification of the fisheries' management goals, which do not correspond necessarily with the ones specified in our model.

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Appendix

The calibration of the model requires information on catchability (q_{ijn}), and labour requirements (l_{jn}), prices (p_i), trip costs (c_{jn}), total available catch (Y), the organisations share of the artisanal quota (CR_{nm}) and the maximum (f^*) effort restriction. q_{ijn}, was calculated as the average of total catches (measured in tonnes) over total effort (measured in trip days) in 2009 for each fish species and vessel type within each organisation. l_{jn} was obtained as the average number of crew members per vessel type, which is equal across organisations. This information was obtained from the Undersecretary of Fisheries' officials. p_i were calculated as the average FOB export price of tonne of fish meal in 2009, multiplied by a factor of 0.12. This is according to personal communications with fish meal plant officials, which is how the price for artisanal landings is calculated. The FOB price was obtained from the Chilean Central Bank's statistics. Trip costs were obtained basically from the FIP (2006). This is a study on pelagic fisheries in central southern Chile, which reports detailed results on trip costs for different vessel sizes in the artisanal sardine and anchovy fisheries. The included cost categories were fuel, lubricants and supplies. The nominal costs reported were updated with the relevant deflators. However, the study does not report costs for small boats. Therefore, in this case, we had to make some assumptions on the variable trip costs for these crafts. Basically, we used the costs for the smallest available vessel category in the FIP (2006) study, which were vessels <15 m long and multiplied the relevant cost categories by a fraction of total reported costs per trip. Finally, Y, CR_{nm}, f^*, were obtained from official documents of the Undersecretary of Fisheries.