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Distribución de la cuota total anual de captura entre los sectores artesanal e industrial en la pesquería de sardina y anchoveta: efectos en ingreso, empleo y equidad

(TAC distribution among artisanal and industrial fleets in Anchovy and Sardine fishery: Trade-offs between profit, employment and equity)

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Resumen

En esta tesis se plantea un modelo de optimización multiobjetivo para la pesquería de Sardina Común (Strangomera bentincki) y Anchoveta (Engraulis ringers).

El modelo matemático se ha desarrollado con las intención de evaluar los efectos que diferentes distribuciones de la cuota total anual de captura (TAC) entre las flotas artesanal e industrial, puede tener en los objetivos que son importantes para la pesquería considerando las prioridades de los involucrados y visto desde el punto de vista del hacedor de política; lo anterior, en términos de las implicancias para tres objetivos particulares que son la maximización del beneficio económico, la maximización del empleo y la maximización de los niveles de equidad.

Los resultados indican que los intercambios entre beneficio económico y equidad, y entre empleo y equidad no son lineales, lo que significa que las magnitudes de las ganancias o pérdidas de un objetivo de política en función de otro dependerán de la posición sobre la frontera Pareto, sin embargo, y bajo las condiciones planteadas en el modelo, el regulador tendrá incentivos para determinar la distribución de la cuota de tal forma que minimice los conflictos distributivos.

Abstract

A multiobjective economic model was formulated for the Chilean Anchovy (Engraulis ringers) and Common Sardine (Strangomera bentincki) fishery, in order to evaluate the effects that different distributions of the total allowance catch (TAC) between artisanal and industrial fleets can have on a number of targets of interest to the participants in the fishery from the point of view of the policy maker, in terms of its aftermath on three management objectives which are economic profit, employment and equity, to examine the nature and the magnitude of the tradeoffs that occur between these. Generating techniques approach was used, specifically the constraint method.

Results indicate that the tradeoffs between employment and equity, and between profit and equity are nonlinear, this means that the gains or losses of one objective in terms of the other one will depends on the position along the Pareto frontier, and that under the conditions established in the model, the policy maker has incentives to set the TAC that minimizes distributional conflicts. Moreover, the values of the tradeoffs are positively dependent on fish abundance.

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1 Preliminaries

Fish and fisheries are an integral part of most societies and make important contributions to economic and social health and well-being in many countries and areas. As can be seen from Table 1.1 in recent years the global production from capture fisheries has tended to vary between approximately 88 and 90 million tons.

Table 1.1: World fisheries production in million tonnes.

	2006	2007	2008	2009	2010	2011
Inland	9.8	10.0	10.2	10.4	11.2	11.5
Marine	80.2	80.4	79.5	79.2	77.4	78.9
Total capture	**90.0**	**90.3**	**89.7**	**89.6**	**88.6**	**90.4**

Source: FAO (2012). Data for 2011 are provisional estimates.

Latin American fish production has expanded significantly in recent years. With a coastline of about 4,200 kilometers and a 200-mile exclusive economic zone (EEZ), Chile possesses twice as much sea as land and is an important actor in the context of global fisheries and, since the mid-1980s, has been ranked among the most important countries, with catch volumes exceeding 4 million tons. According to FAO (2012) this country belongs to the group of the top ten exporters and importers of fish and fishery products between 2000 and 2010, with a total amount of US$ 3,394 million in 2010.

The crisis in global fisheries is well documented, with 80% of the world's marine fisheries estimated to be over exploited, depleted, recovering from over exploitation or fully exploited (FAO, 2010). This crisis has largely been attributed to governance failure, with the World Bank suggesting that 'weak governance is the main underlying cause of overfishing'. The World Bank and the United Nations Food and Agricultural Organization (FAO) argue that there are strong economic dimensions to the global crisis in marine fisheries (Nunan, 2013).

Considering this situation it is imperative to develop fishery policies in a better way and setting the proper criteria for fisheries management is an essential first step.

According to Seijo et al. (1997) there are three main dimensions to consider:

- Conservation approach: Is usually based on fishing effort regulation under the assumption that once fishing effort is regulated, changes in species abundance could be reversible in a reasonable time period;

• Economic approach: In in the economic discussion of fishery the term "economic efficiency" refers to the use of resources so as to maximize the production of goods and services but policy makers rarely refer to the concept of economic efficiency; on the contrary, they respond more to high unemployment rates, fishery collapse and decline in income levels, with the consequent socio-economic repercussions (Maiolo and Orbach, 1982), and

• Equity approach: Considering an open access condition and decreasing stock abundance some fishers will be more affected than others and this could produce conflicts among fishers, so the major task in the selection of management alternatives resides in how to favor a user group without damaging others. In this context, equity is an important social consideration by which to assess state intervention strategies; however it is difficult to implement, as equal opportunities do not guarantee an equal distribution of non-renewable resources (Seijo et al., 1997).

However is well known that fisheries policies often pursue multiple objectives, which may, in some instances, be in conflict or competition with each other i.e. there is a trade-off between these objectives. It may not be possible, for example, to create or maintain employment and generate increasing volumes of revenue for government while also sustaining stocks and biodiversity and some compromise between these goals has to be achieved before an effective management strategy can be devised.

In Chile, Sardine and Anchovy Fisheries are administered through a total allowance quota (TAC), which is distributed between industrial and artisanal fishers. The proportion of this TAC that is given to each group has been the subject of long conflict and fishery managers are confronted with the problem on how best to allocate this total allowable quota among the artisanal and industrial fleets. 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 (Castillo and Dresdner, 2013).

This paper attempts to shed light on the effects of different distributions of the TAC between artisanal and industrial fleets can have on a number of targets of interest to the participants in the fishery from the point of view of the policy maker, through the development of a multi objective programming model of the Sardine and Anchovy fishery in Chile. For this particular fishery there is not a previous study that analyzes the impact of the distributión of the total allowance catch between differents segments of the fishery on the objectives that the policy maker take into account at the time to develop the policy.

1.1 General objective

To analyze the effects that a reallocation of the total annual catch quota between artisanal and industrial fleets could have on three policy objectives (employment, profit and equity) in sardine and anchovy fishery.

1.2 Specific objectives

- Develop a multi-objective optimization model to find the optimal value for each of the presented objectives.
- To determine the effects of a change in the proportion of the total annual catch quota that is delivered to each sector, in the optimal values of the objectives.
- Evaluate the natures and magnitudes of changes in one of the objectives in terms of the other two (tradeoffs)

In summary, this mathematical model is going to be developed in order to evaluate the effects of the redistribution policies that are used for the management of the fishery, in terms of its aftermath on three management objectives which are economic benefit, employment and equity, i.e. to examine the nature and the magnitude of the tradeoffs that occur between these.

Contrary to what happens in other fisheries worldwide, the state of Chile does not have an official document which explicitly details the objectives sought by fisheries management, so that the objectives that will be analyzed in this study have been determined by analyzing the current policy discussion and the interests of the stakeholders in addition to the existing literature.

A "Multiobjective Optimization Problem" approach is going to be developed using generating techniques (GT), specifically the *constraint method*. This choice is based in that instead of focusing on a single supposedly optimal solution, GT allow the analyst to systematically investigate the range of choice and the tradeoffs involved in the selection of alternative policy options. By focusing on the relationships between the decision variables (policy instruments) and the objectives, results from GT can help decision-makers to better understand the impact of their decision on the environment, user groups, regions and on the overall level of benefits. This information also may help groups with different interest to bargain more efficiently in the policy arena (Sylvia, 1992).

In the following sections a brief overview of the Sardine and Anchovy Fisheries and its regulatory framework, the generating techniques approach and the mathematical description of the model are presented; but before, a brief review of literature on the objectives and choice variables that have been used in literature about multi-objective optimization models, will be presented. Finally , the results and conclusions are presented.

2 Literature Review

The use and regulation of natural resources, both renewable and non-renewable, is a challenge for society as a whole. There are several edges that governments should take into account when they design policies for the management of these resources, especially for those countries where the use of certain types of resources has become one of the pillars of its economy.

Fisheries represent the case of a renewable natural resource where attempts to manage it optimally have been performed testing different regulating systems, without reaching an optimal design that is accepted by all stakeholders.

When making decisions regarding the management of fisheries, regulators need to shuffle many objectives that go beyond pure profit maximization, such as resource conservation, food production, economic benefits, creating an income in line with fishermen´s expectations, maintenance (creation) of employment and ensure the viability of fishing communities, among others (Mardle and Pascoe, 1999).The main problem is that in many times these objectives are in conflict and to achieve a situation where all of them are met becomes very difficult or even impossible.

Fisheries management draws attention from numerous stakeholders with various interests in the fishery, i.e. fishermen, regulators, consumers, environmentalists and labor unions. Therefore, in the management process it can be relevant to consider several objectives in order to implement a regulation, which accounts for the different viewpoints concerning the fishery. Structuring a management model as a multiple criteria decision-making (MCDM) problem allows for including different and even diverging opinions about management goals via a vector of objectives. Trade-offs can be evaluated and the best solution depends on all objectives simultaneously (Kjærsgaard, 2007).

2.1 Objectives of Fisheries Management

The number of objective functions incorporated into a multiobjective programming model depends on the problem at hand and the availability of information on it (Pan et al., 2001).

If fisheries management policies around the world are examined, it is possible to find that the objectives that are usually considered are (*i*) maintaining employment for fishers, (*ii*) generation of economic wealth, (*iii*) food production, (*iv*) resource conservation, (*v*) generation of reasonable income for fishers, and (*vi*) maintaining the viability of fishing communities (Mardle and Pascoe, 1999).

In a very similar way, the objectives of the Common Fisheries Policy (CFP) for the management of the European fisheries are *"to protect and conserve available and accessible living marine resources, and to provide for rational and responsible exploitation on a sustainable basis, in appropriate economic and social conditions for the sector, taking account of the implications for the marine ecosystem, and in particular taking account of the needs of both producers and consumers"* (European Commission, 1992). Responsible exploitation implies economic efficiency and hence considerable weighting can be assumed for this objective, however, "in appropriate economic and social conditions" implies that maintaining employment is also a high priority (Mardle and Pascoe, 2001).

In a multicriteria problem, typically the defined objectives will naturally conflict to some degree. This is often seen in fisheries where there is an almost natural conflict between conservation or biological objectives and economic objectives (Mardle and Pascoe, 2003b).

2.1.1 Conservation

Since fishery is an extremely invasive activity for the marine environment, minimizing the impact that this causes is a huge concern for all the agents involved in this issue.

The "conservation" concept is used to convey both the needs for sustainable fishing and those for environment protection from fishing more clearly.

The fishery environment objective can be described as maximizing the sustainable yield of commercial target species from the fishery and the objective relating to the conservation of marine environment is particularly related to by-catch issues, but does include non-targeted fish species as well as dolphins, whales, etc. (Mardle et al., 2004)

Fishery Environment The management of the fisheries environment becomes a big issue since the optimal administration of this can ensure the sustainability of the resource in a long term and it is because of this that many of the articles in the related literature, takes this as a main objective in the optimization problem.

A main objective in Padilla and Copes (1994) is to maximize economic utilization of fishery resources without endangering the sustainability of resource based, attaining self sufficiency in fish supply, and achieving equitable distribution of benefits.

Placenti et al. (1992) introduced the idea of a ratio between the catch and the maximum catch (vertex of the catch-effort curve), as a way to integrate the biological concept to the problem and Padilla and Copes (1994) limited the total catches for species to the biological potential of the resource and integrated this idea to the model through a constraint.

Marine Environment Usually the gear used into the fishing activity generated a lot of collateral effects to the marine environment e.g. by-catch which can be interpreted as (i) catch which is retained and sold but which is not the target species for the fishery, (ii) species/sizes/sexes of fish which fishermen discarded, (iii) non-target fish, whether retained and sold or discarded, and (iv) unwanted invertebrate species, such as echinoderms and non-commercial crustaceans, and various vulnerable species groups, including seabirds, sea turtles, marine mammals and elasmobranchs, etc. (Alverson, 1994)

Some fisheries activities are very harmful for other protected species. This is the case of the yellowfin tuna fishery in the Eastern Pacific Ocean which causes incidental mortality of dolphins, sea turtles and sharks. Enríquez-Andrade and Vaca-Rodríguez (2004) use multiobjective decision analysis in this context, considering as objectives (a) minimizing dolphin incidental mortality, (b) minimizing by-catch of all non-dolphin species and (c) maximizing total yellowfin tuna catch.

Non commercial fishing has been also included in the multiobjective models, Pan et al. (2001) use as objectives maximizing fleet-wide profits and maximizing recreational trips to evaluate the trade offs between commercial and non commercial fishing.

2.1.2 Socio-economic

Employment It is possible that in areas where fishing is a very important economic activity, other employment opportunities, besides the direct employment on vessels, can be produced (Mardle et al., 2004).

So, employment produced by fishing activity can be separated in "employment in fisheries" which is refer to the numbers of employees that work directly in the vessels , and "employment in coastal areas" which comprises the number of fishers and upstream jobs (wholesalers and processors) generated from the fishing activity.

Direct employment can be computed using the total number of hours worked by crew members, this is the sum of the multiplications of the number of crew members per vessel by the fishing time per vessel(Mardle and Pascoe, 2001), or using the labor component for every unit of standardized fishing effort (Padilla and Copes, 1994), while indirect employment is determinate by using employment multipliers from input-output tables (Mardle and Pascoe, 2003a).

Profit This objective is the classical economic assumption with respect to the objective of producers, i.e. fishermen. It is related to the desire of having the highest return on the invested capital.

One way to measure the economic profit from fisheries is to consider this as the difference between the proportion of net revenue that is not taken by the crew and the cost of all the operating vessels (including the non-cash costs such as depreciation and opportunity costs). Mardle and Pascoe (2001) made the assumption that the remuneration system would continue in fisheries i.e. the proportion of the net revenues that belongs to the crew will be fixed. Economic profit can be also specified by assuming the cost as a linear function of the total fishing effort for the different types of gear (Placenti et al., 1992).

Safety and Labor Conditions Securing safe and reasonable working conditions on board the vessels can be relevant in order to attract and keep employees in the fishing sector.

But safety is a very difficult attribute to measure because it is not a tangible objective, however there is a lot of ways to put this into numerical terms e.g.

number of employees, size and condition of the vessel, number of accidents or labor's diseases and so on.

Kjærsgaard and Andersen (2003) use as objective the maximization of the maintenance cost, which includes cost for maintenance of vessel, machines, electronic equipment and other assets, this considering that the higher these costs are, the more being done to keep the vessel in an updated working order, while (Mardle and Pascoe, 2003a) modeled labor conditions through the relative impact of different gear types in the issue of safety.

2.1.3 Other

Minimize Conflict Between Stakeholders Since fishery rationalization entails an inevitable displacement of vessels and fishers, an important issue to resolve is from which fleet and sector this reduction should come.

For equity purposes it is considered that management regulation should not favor any group, so in the allocation process the current proportion of fishing effort exerted by all the sectors should be maintained (Padilla and Copes, 1994). Another way to take in account this issue is considering fisheries that are managed by a group of countries. It is possible that as a way to avoid conflicts between the stakeholders, the maintenance of the relative historic quota shares amongst countries can be inserted as a an objective in the model (Mardle et al., 2000).

Reduction of conflicts between fishermen who use different fishing gears and conflicts between fishermen affiliated and non-affiliated to a determined association has been treated in literature as well (Mardle and Pascoe, 2003a).

Political Effective management often requires compromise to obtain agreement and compliance by all participants. In the European Union, this compromise has been enshrined in the "principle of relative stability", which ensures that no single member state benefits to a greater extent than any other from management decisions concerning the common poll fisheries. This agreement has been included as an objective in (Mardle and Pascoe, 2001).

Sometimes governments have agreements with the actors in the fisheries activity that obligated them to try to maintain certain levels of activity e.g. in the industrial fishery. Kjærsgaard and Andersen (2003) considered this political issue on the analysis of the Danish industrial fisheries in the North Sea decomposing this objective into into two measures in form of activity and capacity. Activity is measured as the sum of days at sea times kW per day, while capacity is measured as the sum of vessels times tonnage per vessel. The activity measures are thus directly related to the measures used in effort and capacity regulation in the European Union.

2.2 Choice Variables

Harvest, effort, number of vessels, type of gear, length of season, entry/exit rules are among the choice variables frequently used. The choice of objectives and choice variables, as well as implicit model constraints and system formulation, depend on the fishery being considered. However, the dominant part of the above mentioned objectives are common to most commercial fisheries (Kjærsgaard, 2007).

In most cases, the variables optimized is fishing effort distributed over either different regions, gears or tonnage classes, because this is an important decision variable in fisheries management.

In a lot of countries, effort control—such as limited entry, seasonal closures, area closures, and effort quotas—is a common practice in fisheries management. In heterogeneous fleets with respect to vessel sizes, gears, targets, fishing grounds, fishing seasons, and motivations, a comprehensive measure of effort is needed to capture the variations of the fishing activities in the fishery. Effort can be measured in terms of numbers of vessels which are described by fleet (i.e. main gear type used and location fished) and size (Mardle and Pascoe, 2001).

In Pan et al. (2001) fishing effort is expressed not only in terms of the number of vessels in various fleets (fleet mix) but also in terms of fishing strategies to capture the variations in fishing activities. In other words, the model not only selects the number of vessels from different fleets but also selects fishing strategies, such as targeted species in different fishing grounds during various seasons, to achieve fleet-wide optimal objectives. Thus, fishing effort can be represented by the use of a set of four-dimensional decision variables. The four dimensions are fleet categories, targeted species, fishing areas, and fishing seasons.

Another choice variable that is very popular in the optimization literature is the allocation of the total allowable catch. In the literature the optimization approach has been used to determinate the optimal allocation of catch across competing fleets (Padilla and Copes, 1994), the allocation of catch between the participating countries that achieves the best mix of outcomes given the various objectives (Mardle et al., 2000), to allocate the total allowable catch among the vessels groups while considering total regional employment and the income issues (Leung et al., 2001), etc.

2.3 Conclusion

While it is true that there are many applications of multi-objective optimization in fisheries, they are all quite different. Since each fishery has its own characteristics and attributes, as well as their own problems, the design of a multi-objective maximization problem is unique for each of them.

By analyzing existing literature, it is clear that the objectives to be maximized are quite similar from one application to another, and generally can combine into four major groups: biological, economic, social and political, which meet the main concerns of the involved agents, however, how to address them is not always the same, which poses challenges when designing a multi-objective optimization problem for a particular fishery.

3 Management of the Sardine and Anchovy Fisheries

Anchovy (*Engraulis ringens*) and Sardine (*Strangomera bentincki*) 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 (Castillo and Dresdner, 2013).

Acording to Zúñiga and Canales (2012) the anchovy stock is currently overfished and overfishing is occurring. Total biomass in 2012 was estimated at around 218,000 tons and spawning stock biomass at around 78,000 tons, which is considerably below estimates from previous years, while for sardine the stock is considered to be "healthy", far from overfishing and overexploitation.

According to the Chilean Fishery and Aquaculture Law (FAL, 1991) the total fishing fleet it can be separated in two main groups: the artisanal and industrial fleets.

An artisanal fisher is defined as an individual who works on the sea as a crew member and/or owns a boat/vessel, or has a maximum of two boats/vessels, which jointly do not exceed 50 gross tons; and the industrial fleet includes vessels above 50 gross tons.

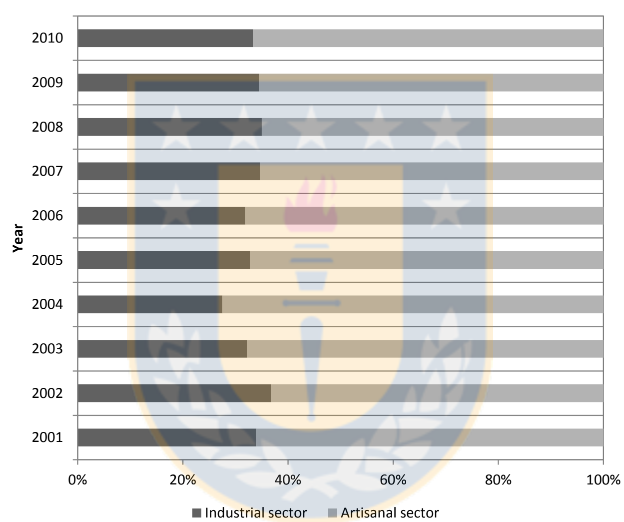
For the past years and up to 2012, the management of the common sardine and anchovy fisheries was executed in the following way: Fisheries Development Institute (IFOP for its Spanish acronym) delivers its stock assessment report and TAC recommendation to the Sub-secretariat of Fisheries (SUBPESCA for its Spanish acronym). SUBPESCA, in turn, writes its own technical report, summarizing the status of the fishery and issuing its own TAC recommendation to National Fisheries Council (CNP in its Spanish acronym), along with a proposal for the distribution of the quota.

The CNP discusses the report and agrees (or rejects) an annual quota and its distribution between sectors and this quota is then signed into force by the Minister of Economy, Development and Tourism, in accordance with the Fisheries and Aquaculture Law N° 18,892 (IFOP, 2009).

TACs are in place since 2001 and are split to accommodate commercial (both industrial and artisanal sectors) and research purposes. Since this fishery is managed in an adaptive way, TACs change during the year to accommodate new scientific information.

Figure 1 shows the evolution, during the past decade, of the distribution of the TAC between the two fleets. It is clear that the distribution has not changed significantly over the years and has remained between 63% and 72% for the artisanal fleet, and between 36% and 27% for the ndustrial fleet.

Figure 1: Distribution of the total allowance catch (TAC) between industrial and artisanal fleet since the year 2001 to 2010 in sardine and anchovy fishery in Chile (percentages).

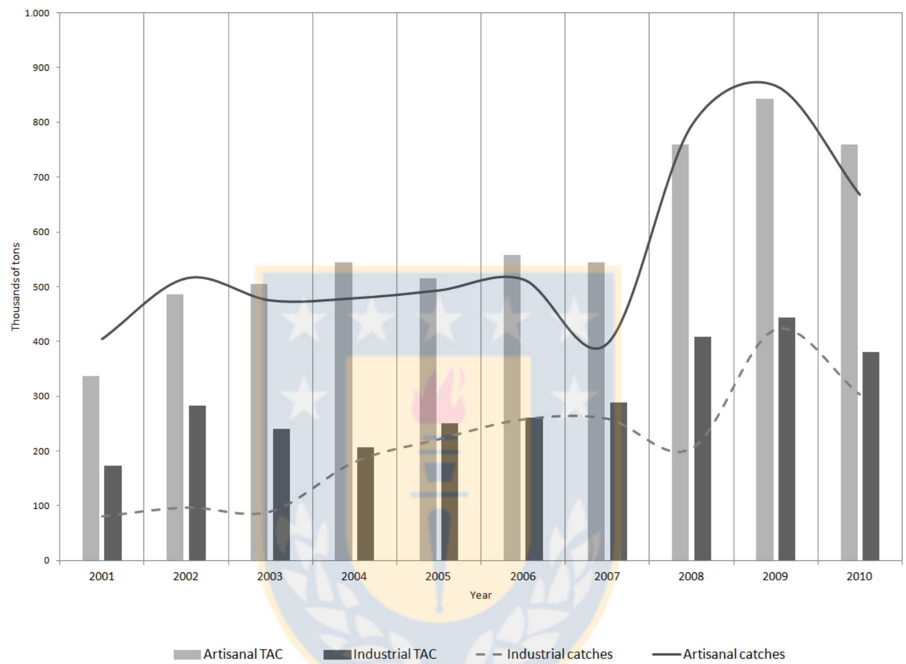


Source: Servicio Nacional de Pesca, Chilean Government.

Currently, new access to this fishery is prohibited. A individual quota system called “Maximum Catch Limit per Vessel Owner” has been established for the industrial sector as well as an “Artisanal Extraction Regime” (collective quota system) for the artisanal sector (IFOP, 2009).

Since 2001 to 2010, artisanal landings were above the permissible limit a few times, while during the years in which this limit is not exceeded, the catches were very close to the maximum established. Conversely, the industrial landings have remained under the assigned TAC , it is even possible to see that in at least four opportunities the catches were less than half of the allocated quota (see Figure 2).

Figure 2: Comparison between the allocated quota and capture on sardine and anchovy fishery in Chile, between the years 2001 to 2010 for the artisanal and industrial fleets.

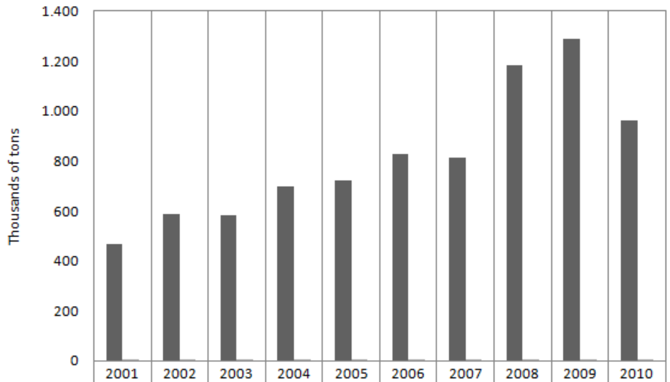


Source: Servicio Nacional de Pesca, Chilean Government.

The entire capture is processed in the same plants. Usually the industrial fleet and the processing industry are vertically integrated, this means that all the catches are entirely delivered to the plant for processing, as well as the catch from the artisanal fleet.

Almost 100% of the sardine and anchovy landing are transformed in fish meal, and just a very small amount of the catches is used for another final products. (See Figure 3)

Figure 3: Destination of the landings by final product.

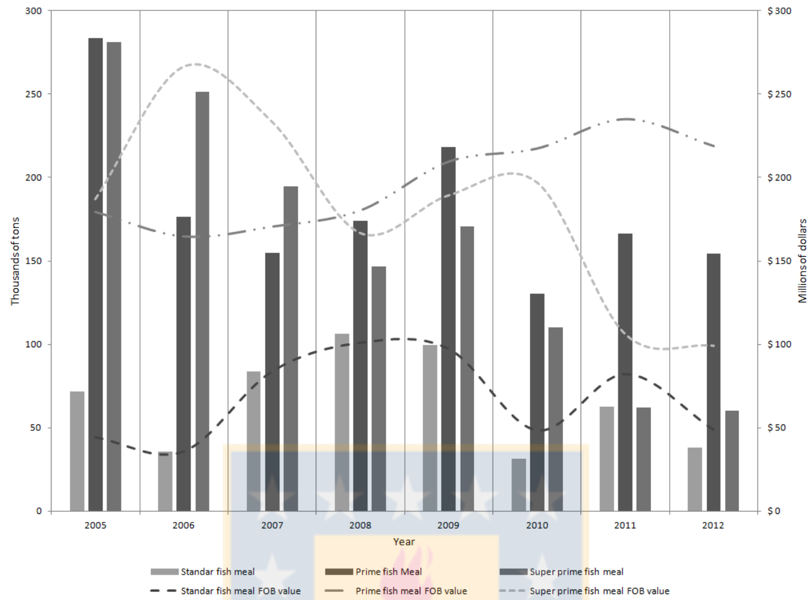


	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fish meal	470	588	583	699	724	826	813	1.182	1.289	964
Others	0,4	0,3	1,7	0,6	0,6	1,4	0,7	1,7	1,9	0,5

Source: Servicio Nacional de Pesca, Chilean Government.

There are three principals types of fish meal, depending on the quality of the raw material used for its elaboration. These different types of fish meal have different prices in the international market. Figure 4 shows the evolution of the amount exported of the differents types of fish meal as well as the total value of this exportations over the years.

Figure 4: Fish meal exportation and FOB value.



Source: Servicio Nacional de Pesca, Chilean Government.

4 Model

4.1 Methodology

4.1.1 Multiobjective Optimization Problem

Formally and without loss of generality, a Multiobjective Optimization Problem (MOP) is defined as:

$$Max\ (or\ Min)\ f(x) = [f_1(x), f_2(x), ..., f_k(x)]^T$$

$$Subject\,to\,\mathrm{x}\,\epsilon\,\mathcal{X}$$

The vector $\mathrm{x}\,\epsilon\,\mathbb{R}^{\mathrm{n}}$ is formed by n decision variables representing the quantities for which values are to be chosen in the optimization problem. The *feasible set* $\mathcal{X} \subseteq \mathbb{R}^{\mathrm{n}}$ is implicitly determined by a set of equality and inequality constraints (Jaimes et al., 2009).

Typically, as a solution strategy, multi-objective problems are aggregated to form a single objective function leading to a single solution for the aggregated function. The solution found using this approach is strongly dependent on the way the objectives have been aggregated. A rather practical approach to deal with multi-objective problems is to find a set of solutions, (called a Pareto set), instead of finding a single aggregated objective-dependent global optimum.

A solution is said to be Pareto-optimal if it is not dominated by any other feasible solution (i.e. there exists no other solution that is better for at least one objective function value, and equal or superior with respect to the other objective functions values). Thus, all of the Pareto solutions are equally important and all are the global optimal solutions (Agrawal et al., 2004).

The concept of Pareto optimality has been widely used in the decision-making processes and the mathematical programming techniques that are used to solve a MOP can be classified regarding how and when to incorporate preferences from the decision maker into the search process. A way to make this classification is regarding to the moment when the decision maker is required to provide information about the preferences, i.e. prior to the search, during the search and after the search (Jaimes et al., 2009).

Generating Techniques are a posteriori preference approach and its greatest advantage compared to other techniques is that puts a relatively small burden on decision makers in terms of the supply of information; decision maker need only to react to the results of the solution process. The emphasis is on the demarcation of the range of choice, not on the explicit definition of preferences.

4.1.2 Generating Techniques

The aim of the generating methods is to provide all the information that can be derived from a multiobjective model, without the need for explicit preferences (or value judgments). The most common of these techniques is the weighting method and the constraint method (Mardle and Pascoe, 2003b).

The general form of the weighting method has an objective function to be minimized or maximized, and a set of constraints.

$$Max\ (or\ Min) \sum_{i=1}^{k} w_i z_i(\mathbf{x})$$

subject to

$$\mathbf{x} \,\epsilon\, \mathbf{X} \tag{1}$$

$$\mathbf{x} \geq \mathbf{0} \tag{2}$$

where $\mathbf{x} \,\epsilon\, R^n$ is the set of decision variables, $z(\mathbf{x})$ is the set of k objective functions, and w_i are the weights associated with each objective, such that $w_i \geq 0$, $\forall i$ with $w_i > 0$ for at least one i. Thus, optimal solutions can be generated by parametric variation of w_i , initially set with arbitrary values.

Similarly, the mathematical representation of the constraint method is:

$$Max\, z_j(\mathbf{x})$$

subject to

$$\mathbf{x} \,\epsilon\, \mathbf{X}$$

$$z_i(\mathbf{x}) \geq b_i \quad (i \neq j)$$

$$\mathbf{x} \geq \mathbf{0}$$

where b is a vector of lower bounds on $(k1)$ objectives $\mathbf{z}$, for all i except $i = j$.

The set of non inferior solutions can be produced by parametrization of w_i and b_i for each method, respectively. Hence, the methods generate (all) optimal solutions from which the decision-maker can then adopt the solution that most closely represents their perception of the best scenario. Therefore, no a priori assessment of decision maker preferences is required. The constraint method has the advantage that Pareto efficient solutions will be determined, and it can also be argued that parametrization of objective lower bounds is more straightforward (Mardle and Pascoe, 2003b).

According to Padilla and Copes (1994) the main advantage of the technique is that the subjectivity in the modeling process can be removed as weights and target values of the goals do not need to be preassigned. Instead, the decision-maker can be presented with a 'menu' of potential solutions from which the desired allocation could be chosen. In addition, the technique makes explicit the tradeoffs between objectives that are not observed in a single objective model (Sylvia and Enriquez, 1994).

The constraint method

The basic idea is to transform all but one objective to constraints with unknown right-hand side values which represent different target values or achievement levels. For any set of right-hand side values, the problem is but a standard linear programming problem(Eiselt and Sandblom, 2007) .

After the problem is solved for one set of achievement levels, their values are modified by the decision maker and the problem is solved again with a different set of right-hand values. This process is repeated in order to find a set of points that form the Pareto frontier.

4.2 Control Variable

The main aim of this investigation is to determine the effects of the different distribution of the total allowance catch (TACs) for the sardine and anchovy fishery between the artisanal and industrial fleets in three policy objectives.

The control variable is going to be the proportion of the TAC that is given to each fleet by the policy maker.

In order to ensure that the allocated catch equals the amount actually captured, two assumptions will be considered: the first one refers to the profit functions of both fleets, which will be assumed as linear (i.e. the maximum possible revenue is generated when the total allowed catch is captured) and known by the regulator, thus, the policy maker can directly influence the decision of the agents about how much to capture; the second one refers to the ability of the policy maker to supervise both fleets and force them to capture only the quota assigned (i.e. perfect supervision),in other words, a perfect compliance situation is assumed.

As TAC and its distribution are determined annually, the period of study is going to be a whole year; therefore all the considered information for the model (costs, employment, prices, etc) will be annual. It is important to note that the part of the TAC destined to research purposes is usually earmarked to the artisanal sector and this is how is going to be included in the model.

4.3 Objectives

Three objectives are going to be considered as goals for the policy maker: maximization of profits, maximization of employment, and minimize conflict between fishergroups.

These objectives have been chosen by analyzing the current policy for the fishing industry, the most common conflicts that have been taken place between the stakeholders, and the issues that have been most commonly considered in the specialized literature, inter alia.

4.3.1 Maximize profit

The most common objective for public sector problems is economic efficiency. For economists economic efficiency is the maximization of net national income benefits. It is claimed, from neoclasical economic theory that the attainment of economic efficiency assures a state of maximum social welfare when the assumption of pure competition is not violated. Since this is never the case in the real world, the maximization of the net national income benefits, although an important indicator of the social value of an alternative, does not guarantee the maximization of social welfare, which is one of the original motivation for multiobjective planning (Cohon, 2004).

Fisheries exist to meet social and economic demands and one would expect to find that the impact on the resources has resulted in a measurable economic benefit. For the policy maker is important that the participants in the activity make a profit in order to ensure their continued participation in the activity and the country can continue to obtain the economic and social benefits to the fishery generates.

In the model, profit is going to be measured as the total net income produced by the fishery (TIF) at the commercial level (considering both exports and domestic consumption). According to Sylvia and Enriquez (1994), the justification for aggregating the net revenues of harvesters and processors is based on two main factors: first, harvest and processing are highly interrelated activities. Not only do they take place at-sea as part of a continuous and vertically integrated operation, but where and how fishermen harvest can influence the choice of product forms, yields, quality, and product value. Secondly, production of alternative product forms can make an important difference in terms of the economic benefits obtained from the fishery, e.g. according to the landing quality, differents types of fish meal can be produced each with a different price.

In Chile, the anchovy and sardine landed by artisanal and industrial fleets are processed in the same processors plants. However due to the different quality of the catch, the final products that can be obtained from this two catches are different and so are the benefits that each of the fleets can generate e.g. different qualities of fish meal (prime, super prime, standard).In the model, this is represented by the assumption that all the artisanal catch will be transformed into standard fish meal while industrial catch will be used to produce different proportions of standard, prime or super prime fish meal.

It is well known that the difference between each type of fish meal is given by the quality of the raw material used in its production. Because of their better storage conditions, industrial vessels are able to maintain catch in better condition, and this is why it is assumed that this catch can be transformed any type of fish meal.

In the short run, profit is measured as the total yearly contribution margin i.e. catch value less variable costs. In the short run scenarios it is assumed that fixed costs do not influence the behavior of the vessels.

4.3.2 Employment maximization

Social welfare is one of the reasons for the existence of the policies governing the use of natural resources; in the case of fisheries, this ”welfare” is translated e.g. at the number of people who are employed directly or indirectly by the fishery.

This study only considers the direct employment produced by the fishery. Direct employment is computed as the total of workers that participated in the fishing activities, i.e. the total number of artisanal fishermen and workers from industrial fishing fleet and processing plants.

The employment for the fleets will be calculated as the number of annual work units (awus) i.e. as total days worked divided by the average annual number of days worked in full-time jobs. For the processing industry, on the other hand, the employment will be the annual average of employees on the industry during 2009.

As discussed previously, the difference between the artisanal and industrial fleets is given by the size of the ships in the fleet.The different sizes boats need different amounts of employees to operate, in particular due to higher productivity in catches of industrial ships, the number of workers needed to capture a ton of S & A will be lower, which means that if the proportion of the quota that is given to this fleet increases, the total employment will decrease.

4.3.3 Equity

It is clear that a major social constraint in fisheries management is that human societies and behavior are not easily transformed and fishing families and communities may not be willing to move into other occupations, or away from their normal homes when there is surplus capacity in a fishery, even when their quality of life may be suffering as a result of depleted fish resources. The problem is much worse when there are no other opportunities outside of fisheries in which they could earn a basic living (Cochrane, 2005).

For equity purposes it is considered that management regulation should not favor any group, so in the allocation process the current proportion of fishing effort exerted by all the sectors should be maintained (Padilla and Copes, 1994). Another way to take in account this issue is considering fisheries that are managed by a group of countries. It is possible that as a way to avoid conflicts between the stakeholders, the maintenance of the relative historic quota shares amongst countries can be inserted as an objective in the model (Mardle et al., 2000).

In Chile the artisanal sector is has been usually in conflict with the fishery management system arguing that they have been in a unfavorable situation compared to industrial sector in regard to the fishing regulations.

As a way to measure this "conflict situation", a distance is going to be calculated, relating the amount of the total allowance catch that is given to the artisanal sector with the historic proportion that have received, in order to measure the changing in the welfare for the artisanal fleet.

Usually equity is used to indicate fairness or justice. In the analyzed fishery, the current distribution of the total allowance catch is the result of constant and successive negotiations between the artisanal fleet and the regulator. During 2001 to 2006 the proportion of the TAC that artisanal fleet has received fluctuated, but since 2007 it remains relatively constant. (See figure1)

Since this stability in TAC distribution has been the results of agreements between all the stakeholders, it can be considered as a fair situation, in other word could be called an equitable allocation and any change in distribution will be considered as a loss of equity. The equity function will be represented using a natural base exponential function, using as exponent the absolute value of the difference between the historic proportion of the TAC given to the artisanal fleet and the value given to them by the model.

4.4 Mathematical model

Considering all this, the problem for the policy maker is to maximize the net profit and the total employment while minimize the conflict between the fishers groups, controling the amount of the total allowance catch quota that is shared between the industrial and artisanal fleets, which mathematically can be summarized in the following equations.

Equation 3 represents the control variable i.e. the proportion of the fishing quota for each fleet i , modifying τ_i , the regulator can handle the total allowance catch of both fleets.

$$Q_i = TAC * \tau_i \tag{3}$$

Where:

- TAC is the Total Allowance Catch determined by the regulator (in tons). For the model TAC will considered as fixed.
- τ_i is the proportion of the TAC for each fleet i ($i = 1$ for artisanal fleet and $i = 2$ for industrial fleet).
- Q_i is the total amount of the TAC captured by the fleet i (in tons).
- Additionally, the model considers the TAC is completely catched, i.e. $\sum_i \tau_i = 1$, and each fleet is perfectly capable to catch the entire TAC, i.e. there is no capacity restriction for neither of the fleets.

$$Max_{Q_i}\, TIF = LB + PB = \sum_i \left[Q_i(ep_i - cvc_i) + \left(\sum_j coef_j * Prop_j * Q_i \left(p_j - pvc_j\right) \right) \right] \tag{4}$$

$$LB = \sum_i \left[Q_i(ep_i - cvc_i)\right], \quad PB = \sum_i \left[\sum_j coef_j * Prop_{i-j} * Q_i \left(p_j - pvc_j\right) \right]$$

In equation 4 TIF is the aggregate net profits obtained from the capture and the processing and commercialization (this two last activities are going to be considered together).

Landing benefits (LB) are defined as the difference between the ex-vessel price (ep_i) and the unit variable costs (cvc_i) of the fleet i multiplied by the landing in tons, while the processing benefits (PB) are obtained from the difference between the price (p_j) and the unit cost of production (pvc_j) of every final product j (which includes processing cost and storage, transport and any others costs), where $coef_j$ is the conversion ratio, i.e. the percentage of raw material (in tons) that is landed by the fleet and is transformed into the final product j, and $Prop_{i-j}$ is the proportion of the catch that is destined to each final product j by each fleet i . (There are four final products: 1: fish oil, 2: standard fish meal, 3: prime fish meal and 4: super primer fish meal.)

$$Max_{Q_i}\, TE = \left[\sum_i Q_i \left(fe_i + \sum_j coef_{ij} pe_j \right) \right] \tag{5}$$

|

Equation 5 represents the total number of workers employed in the fishery, fe_i is the average number of employees needed to capture each tonne of fish captured by fleet i, and $pe_j$the average number of employees needed to process and commercialize one tonne of the product j.

$$Max\ CS = \frac{1}{e^{|HP-\tau_1|}} \tag{6}$$

Equation6 shows the equity objective which refers to minimize the difference between the historic participation of the artisanal fleet in the total allowance catch and the actual proportion that is given to them (τ_1); specifically , the equity objective is to maximize the reciprocal of a natural base exponential function, using as exponent the absolute value of the difference between the historic proportion of the TAC given to the artisanal fleet and the value given to them by the model. The reason for using the natural base exponential function is to show that the greater the absolute difference between $\tau_1$and HP, the faster the value of the equity function will move away from its optimal value. The historic proportion (HP) is calculated as the average from the TAC given to the artisanal fleet since 2001 to 2010, and is equal to 0.6674.

4.5 Sources and Data

The sources of information that have been consulted for determine the values of the parameters for the model are:

The national fisheries and aquaculture census, which was conducted in 2008-2009 by the National Statistics Institute (INE), covering the small-scale, industrial, aquaculture sectors and their sub-sectors. For the fishery sector, the census includes information about raw material supplies for manufacturing industry, employment, costs, etc.

Additionally there is information provided by Undersecretary for Fisheries and Aquaculture related, among others, to:

- Manufacturing industry, which includes information about raw material suppliers, numbers of employees, amount of final products, etc. for the period 2005-2011.
- Final products prices and the amount of export of each, as well as the destination of this for the period 2005-2013.

- Numbers of fishing trips and landings for the artisanal fleet, for the year 2009.

Is well known that it is not easy to obtain information about operating cost for this two analyzed fleets as well as the processing cost for the manufacturing industry.

For the model this information was calculated using different estimates that have been executed in the specialized literature. The available estimates for industry, includes processing costs but no data about commercialization cost or any other associated cost.

The value used is the estimated in Peña and Cerda (2006), and corresponds to the value of processing a ton of fish meal. This value corresponds only to the plant level processing costs and does not include transportation, storage or any other costs. To approximate the missing values, net profits values obtained for the industry were considered. There are not available data about the additional costs that must be considered in order the get the total cost of fish meal.

As a way to approximate this missing values net profit obtained in the industry was considered. The difference between the sale price of fish meal and net benefit delivers the total cost. The processing cost is subtracted from this total cost and so an approximate cost of storage, transportation and any other costs incurred are obtained. In order to get a realistic value for the net income that can be produced by the fishery, EBITDA (earnings before interest, taxes, depreciation and amortization) indicator for the main Chilean companies in fish industry was analyzed for the years 2009 to 2014, considering an average between the returns over the years, is possible to approximate the net profit for the processing industry in 14%

Appendix 1 shows the main data used to produce the parameters included in the model and how they were calculated.

5 Results

The first step is to optimize each function separately in order to determine the maximum or minimum values that can be achieved and to obtain upper or lower bounds for the problem. (All optimizations were performed using the software LINGO©)

The three functions were optimized; each at the time without considered the others two. The results obtained are presented in the following table, as well as the associated values for the control variable.

Table 5.1: Optimal values for objective functions

Objective Function	Optimal Value	τ_1	τ_2
Profit	CLP$ 95,859 million	0	1
Employment	2,337 awus	1	0
Equity	1	0.6674	0.3326

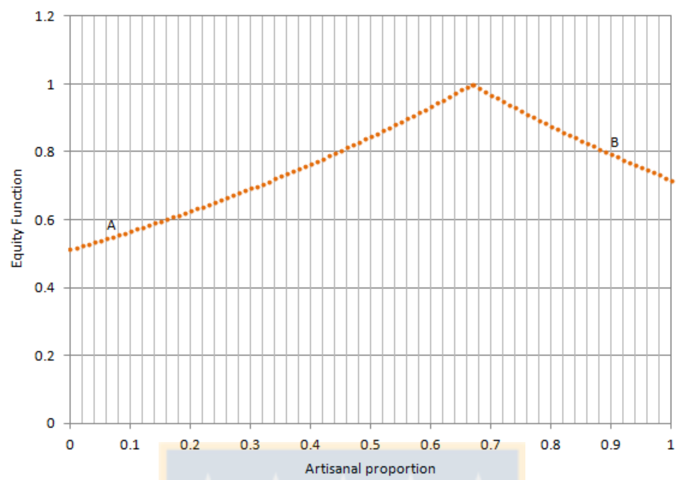
Source: Compiled by author

As observed in Table 5.1, the maximum value for the profit function is given when the total amount of the total allowance catch is conceded to the industrial fleet; this situation is explained by the higher productivity of the industrial fleet, i.e., this fleet is capable of capturing the total quota at a lower cost so it can produces greater benefits, on the other hand industrial landings can be transformed into different types of fish meal which it translates on higher revenues for the fishery.

The maximum value of the employment function is accomplished when the entire TAC is given to the artisanal fleet, this is because artisanal fleet is more intensive in use of labor, therefore it will be able to capture the total quota only using a larger number of workers.

The optimization of the equity function results in a value of 1, as can be seen in Figure 5.

Figure 5: Equity Function



The optimal value for the function is achieved when the amount of the TAC that the regulator gives to the artisanal fleet is exactly equal to the historic proportion that they have received. When τ_1 raises, the value of the equity function decreases from 1 and gets a minimum of 0.717 when τ_1 is equal to 1, if τ_1 decreases starting from 0.6674 (which necessarily means that τ_2 increases), equity will decreases until gets a minimum value of 0.513. This occurs when the entire TAC is given to the industrial fleet.

Figure 5 illustrates this situation; both, point A and point B, represents "inequality" situations but point A shows a higher level of it than point B, in others words, given the entire TAC to one fleet will result in a not equity situation, but this one could be worse considering which fleet receives the full quota

After maximize/minimize each function, is possible to obtain the different values of the other two functions when the third one is optimized.

Table 5.2 shows these combinations:

Table 5.2: Optimal values and associated levels for non optimized functions

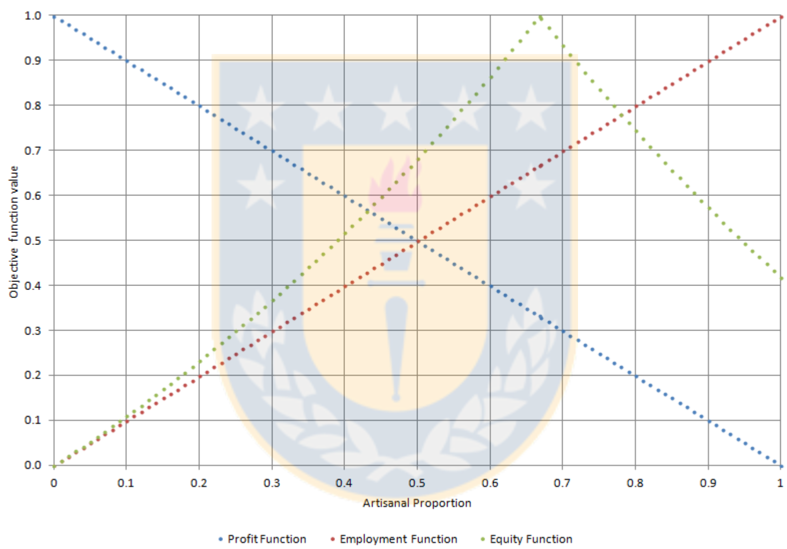
	Maximum Profit	Maximum Employment	Maximum Equity
Profit (CLP million)	**$95,891**	$58,483	$70,925
Employment (awus)	1,859	**2,337**	2,178
Equity	0.513	0.717	**1**
$\tau_1;\tau_2$	*(0;1)*	*(1;0)*	*(0.6674;0.3326)*

Source: Compiled by author

As can be seen in Table 5.2, the maximum profit is accompanied with certain levels of equity and employment, if from this point we move to the maximum employment , the associated income dismiss and the value of the equity function will increases. If the optimal point of the equity function is observed, it is clear that is associated to a lower occupation and profit compared to the optimal values of this two functions, which in other words it means that there are tradeoffs between functions.

Rescaling each objective function is it possible to observe in Figure 6 how they fluctuate together when control variable varies.

Figure 6: Objective functions values



As discussed, maximum profit is associated to τ_1 equals to zero, which means that τ_2 is equals to 1 and maximum employment is achieved when τ_1 is equals to 1. Figure 6 shows that while profit dismiss with an increase in τ_1, employment increases constantly.

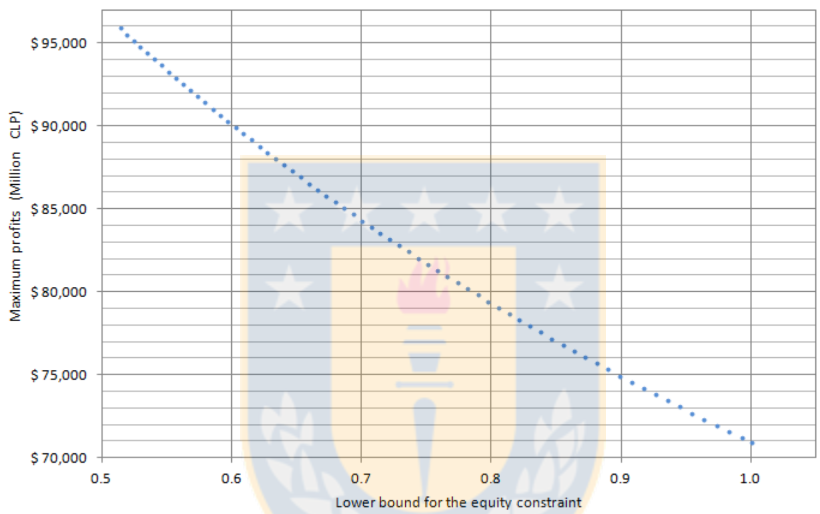
Next, every function is maximized, using the others as a constraint.

The first upper/lower bound for the functions used as constrain will be the minimum/maximum value that was previously obtained by optimizing every function individually (Table 5.2). For subsequent optimizations, the bounds will be modified in order to evaluate the change in the function that is being optimized.

The first optimized function is profit. Equity is using as a constraint and the first considered lower bound was 1.

Figure 5 shows how, when the lower bound for the constraint goes down, the maximum profit rises up obtaining it maximum value when the equity function can be greater than or equal to 0.513, this is when the entire TAC is given to the industrial fleet. (Full results can be found on Table A.11)

Figure 7: Trade off between optimal profits and equity

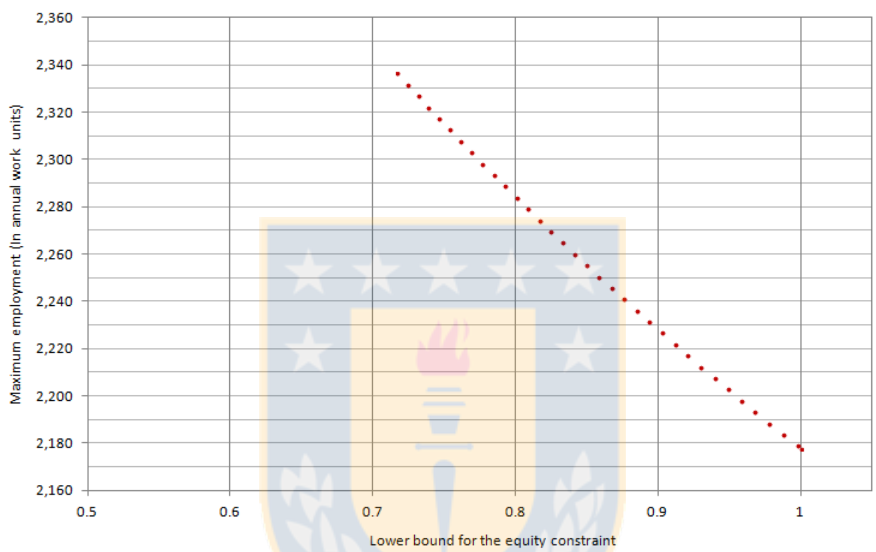


As equity function is the reciprocal of e raised to the absolute value of the difference between the historic proportion and the proportion for the artisanal fleet, and the sum of the τ_1 and τ_2 must be equal to 1, it is clear that is possible to get the same value for the equity function using different combinations of proportions of the TAC for each fleet. However, as can been seen in Table 5.2 in order the get higher levels of profits, the industrial proportion of the TAC must be increase, and this is why the optimization of the profit function only considers values of equity lower than 1 caused by proportions for the industrial fleet higher than 0.3326. Similarly, when employment is optimized (using equity as a constraint) the values that are considered are those produced by values of artisanal proportions higher than 0.6674. (See figure 6).

In a similar way the employment function was maximized. (Full results can be found on Table A.12)

As can be seen in Figure 8 , the employment that is possible to achieved when the equity function is greater than or equal to 1 , is 2,178 annual work units, when this lower bound is dismisses employment increases until gets 2,337 annual work units, which is the maximum value for the function (this is when the entire TAC is given to the artisanal fleet).

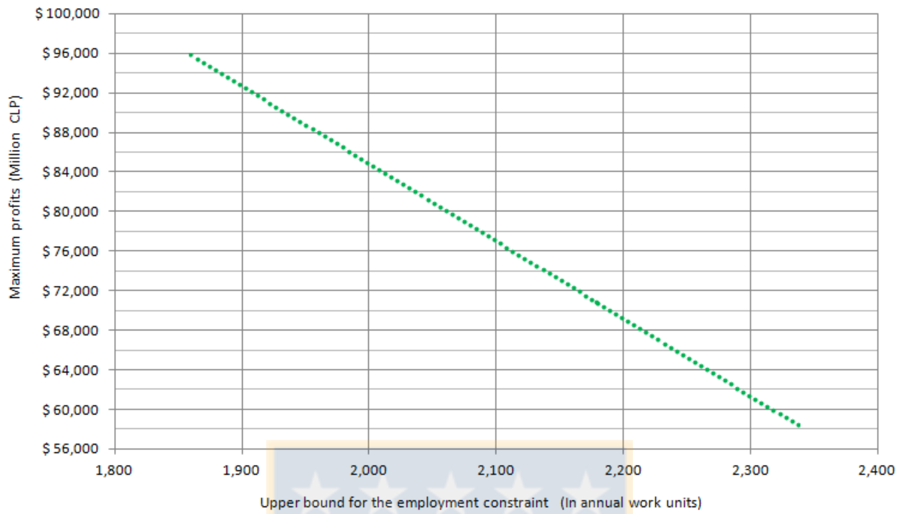
Figure 8: Trade off between optimal employment and equity



Finally the profit was optimized using the employment function as a constraint. (Full results can be found on Table A.13)

The first upper bound for the constraint was 2.337 annual work units; this value was getting smaller until achieved 1.859 awus; at this employment level is possible to get the maximum profit (see Figure 9).

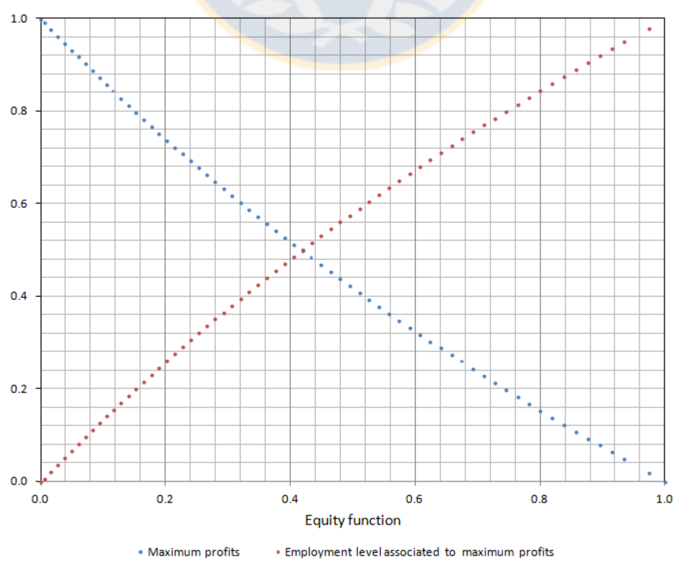
Figure 9: Trade off between optimal profits and employment



In order to observe the tradeoffs between the three objectives, the results have been rescaled.

Figure 10 shows the tradeoffs when the optimized function is profit.

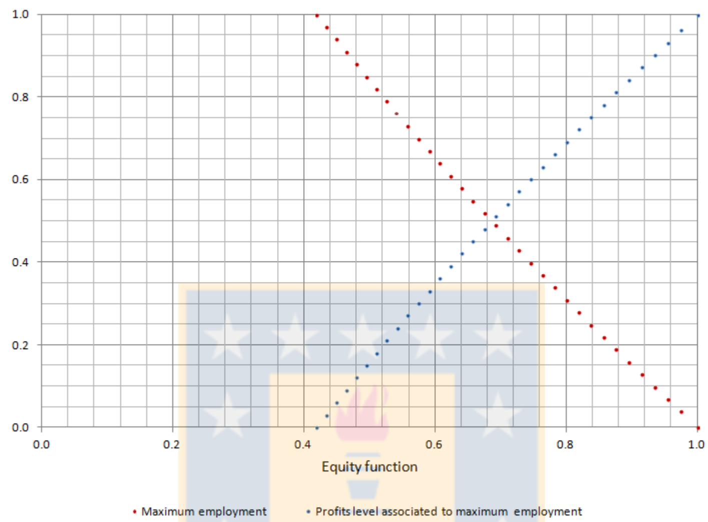
Figure 10: Pareto frontier when profit function is optimized



The same exercise was done for the optimization of the employment function.

Figure 11 shows the optimized values for the function, as well as the associated level of profit given the value of the equity function.

Figure 11: Pareto frontier when employment function is optimized



The marginal rates of substitution were calculated between profit and employment, profit and equity, and employment and equity, in order to observe the trade offs between the three functions. (Full results can be seen in table A.9)

As discussed previously, it is possible to the regulator to achieve higher levels of profit by increasing the industrial proportion starting from the maximum value of the equity function, so the tradeoffs for the model, when the main objective is profit, will be analyzed for equity values between 1 and 0,5130, this is when the industrial proportion is higher than 0.3326 and when the priority objective is employment, the considered values to evaluate tradeoff are artisanal proportions higher than 0.6674.

From Table A.9 is clear a linear relationship between profit and employment. The marginal rate of substitution between the two objectives remains constant independently of the distribution of the quota between the two fleets. The MRS of employment for profit (MRS_{TE-TIF}) is equals to 78.39, this means that is necessary to give up 78.39 millions in profit to increase employment in 1 awu.

MRS of equity for profit (MRS_{CS-TIF}) is negative when the artisanal proportion is higher than 0.6674, this means that for values of τ_1 between 0.6674 and 1, is possible to increases profit at the same time as equity. When τ_1 goes down from 0.6674, MRS_{CS-TIF} is positive, and became bigger when τ_2 goes up, this means that with higher values for the industrial proportion every additional million in profit will be cheaper in terms of equity. Table A.9 shows that if τ_1 is equal to 0.975 is possible increase equity in one point while profits increases 51,519 million CLP; when τ_1 decreases to 0.750, the increasing in profits is just 41,139 million CLP for one additional point in equity. For τ_1 equal to 0.6, an increase in equity in one point will cost 39,518 million CLP, while if τ_1 is 0,075, this additional equity point will imply a reduction of 72,002 million CLP in profits.

On the other hand, the marginal rate of substitution of equity for employment (MRS_{CS-TE}) moves opposite: when τ_1 is higher than the historic proportion, MRS_{CS-TE} is positive, which indicates that in this range of proportion of the TAC for the artisanal fleet, to improve the employment levels means a reduction on equity; this reduction will be smaller when τ_1 approaches to 1; For τ_1 equal to 0.875, improving equity in one additional unit, costs approximately 595 awus, while this number decreases to 525 when τ_1 is 0.750.

For values of τ_1 between 0 and 0.6674, MRS_{CS-TE} is negative. That is, an improvement in equity means that employment will increase less when τ_1 approaches to 0.6674. If τ_1 is 0.6, one additional point of equity will be equal to 504 awus, while if τ_1 decreases until 0.225, the Pareto requirement will be 734 awus. The results show that around the optimal value of the equity function, the marginal rates of substitution become lower, which means that improving employment or profits starting for the optimal equity function will be less expensive.

If TAC increases, e.g., if it is duplicate, is possible to observe how the direction of the trade offs remains constant, however, one important difference between the base and simulated situations is that the magnitudes of the tradeoff between profits and equity, and between employment and equity also duplicate, that is, theMRS_{CS-TIF} is negative when the artisanal proportion is higher than 0.6674, and positive whenτ_1 goes down from 0.6674, and the marginal rate of substitution of employment for equity (MRS_{CS-TE}) moves in the opposite direction (See Table A.10).

6 Summary and Conclusions

In this paper a multiple objective optimization problem for the sardine and anchovy fishery was developed in order to evaluate the effects of a redistribution policy between the industrial and artisanal fleets, on three different policy objectives.

As discussed before, the Chilean government does not have explicit objectives for its fishery policies, however, there are objectives that are common to most of the regulated fisheries worldwide, and they can be easily annealed in sardine and anchovy fishery in Chile.

From the three objectives considered in the model, two are present in most of the analyzed fishery, and its inclusion is mainly due to the distributional conflicts that artisanal fleet has had with government in regard to the policy applied to the management of the fishery.

The results showed that is possible to get a major level of profit by increasing the proportion of the TAC that is given to the industrial fleet, this because it is more efficient and its operating costs are lower compared to the artisanal fleet.

On the other hand, to get the maximum possible employment, the entire TAC must be landed by the artisanal fleet, this because this fleet uses more labor for each ton of catch. The variability in levels of employment are explained only for the fleets employment, this because once the catches are delivered to the processing plants, there are no difference between them and are processed as a whole, and the numbers of employees in plants remains constant.

If the main goal to the regulator is to minimize the conflict with the artisanal fishers, the proportion of the quota that is given to them must be equal to the historic one; nevertheless this will have a cost in terms of profit and employment levels. Results show that the tradeoffs between employment and equity, and between profit and equity are nonlinear, this means that the gains or losses of one objective in terms of the other one will depends on the position along the Pareto frontier.

When marginal substitution rates are considered, the results show that moving away from the equity maximum value is very expensive for the policy maker in terms of the losses or gains in employment and profits. On the other hand, when the assignment becomes closer to the historic distribution of the quota, the gains are bigger. So, the model proposes that the ”best situation” will be found with values for the quota distribution near to the historical distribution. This might be an explanation why, over the years, we observe actual assignments in this fishery that are very close to the historical distribution. Moreover, the model suggests that the tradeoffs equity -profits and equity – employment are dependent on the availability of fish. When, there is greater resource abundance, these tradeoffs should increase, implying that there is a major pressure to maintain the historical distribution, since the costs of diverging from this distribution are higher. Thus, the model predicts that the moment when it is less costly for the policy maker to introduce changes in the assignment of quota between fisher groups, is when the fish resources are scarce.

It is clear that depending on which is the more important objective for the regulator, the control variable will be modified, nevertheless in order to determine how the fishery should be regulated, the policy maker must be capable to identify what its policy objectives are, and what is its principal goal.

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A Appendix

A.1 Parameters

To calibrate the model, data from year 2009 will be considered, this because this year is one that has the highest level of compliance of the total allowance catch for both the artisanal and industrial fleet.

In order to calculate the total operating cost and the generated employment for the artisanal fleet, it is necessary to consider that this fleet is conformed by vessels with different sizes (type I includes rowboats and motor boats, type II includes vessels with less than 12m. long, type III refers to vessels between 12m. and 15m. long, and type IV are the vessels with more then 15m. long) and each of these perform a number of fishing trips during the year. The numbers of crew members for every vessel type is given by Castillo and Dresdner (2013).

The variable cost for every landed ton is going to be calculated as the sum of the fishing trip cost by vessel size, calculated in Jara (2014), multiplying by the numbers of fishing trips performed during 2009, divided by the total tonnes landed by the fleet, plus the cost of wages paid to the crew which have been estimated in literature as 40% of the ex-vessel price.

Table A.1: Artisanal fleet composition

	Vessel type			
	I	II	III	IV
Annual fishing trips	1,.441	2,079	2,794	15,939
Average crew members	2	5	7	10
Operational cost by fishing trip (CLP)	$ 124,717	$ 407,672	$ 475,960	$ 543,851

Source: Subpesca Databases

The ex-vessel price for the landing is estimated in literature as a percentage of the fish meal average price (12%).

For the model, the ex-vessel price for artisanal fleet is 12% of the monthly average price of standard fish meal during 2009, while the price for industrial landings is calculated as the 12% of the weighted average of the three types of fish meal that those landing produces considering the average price of a ton of each type and the distribution of the catch between those types of fish meal.

Table A.2: Annual price for fish meal during 2009 (CLP /Ton)

Fish Meal Type	**Average Price**
Standard Fish Meal	$ 560,959
Prime Fish Meal	$ 564,099
Super Prime Fish Meal	$ 640,377

Source: Subpesca Databases

The total employment generated by each fleet is calculated as the number of annual work units (awus) i.e. as total days worked divided by the average annual number of days worked in full-time jobs. The total days worked is the number of fishing trips by vessel multiplying by the average crew members which depends on the vessel size, divided by 261 days.

For industrial fleet, operational cost for landed ton and fishing trips have been estimated in specialized literature as well as the total employment in annual work units (see tables A.3 and A.4). The extraction cost by ton for the entire fleet, is determined a weighted average of the operational and extraction cost by vessel type and the fleet composition during 2009.

The vessel type is given by storage capacity of the vessel: type I with less than 700 cubic meters, type II between 700 and 1,000 cubic meters, and type III with more than 1,000 and less than 1,200 meter cubic of storage capacity.

Table A.3: Cost for the industrial fleet

	Vessel type		
	I	II	III
Operational cost by fishing day (CLP)	$ 1,303,914	$ 1,386,773	$ 1,732,207
Cost by landed ton (CLP)	$ 5,531	$ 5,531	$ 6,326

Source: Peña and Cerda, 2006

Table A.4: Annual work units for industrial fleet (2005-2009)

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total worked days	54,491	25,559	34,865	38,636	52,609	56,646
Annual work units	209	98	134	148	202	217

Source: Dresdner et al. (2014)

The employment (in awus) for the processing industry during 2009 it was calculated as the total number of employees working in the fish meal industry weighted by the quantity of sardine and anchovy used as raw material.

Table A.5: Raw material and employment for processing industry

Year	2005	2006	2007	2008	2009	2010
Annual average employment	1,055	1,198	863	2,198	1,995	2,454
S&A used as raw material (Tons)	379,463	622,872	453,388	840,348	1,010,573	877,013
Total raw material (Tons)	1,133,713	1,620,545	1,058,130	1,597,685	1,616,058	1,178,267

Source: Subpesca Databases

The processing cost by final product have been previously estimated in literature (Peña and Cerda, 2006), the storage, transport and any other costs were approximated considering a 14% of net revenue for standard fish meal, while the cost for the raw material depending of the origin of this, i.e. from industrial and artisanal fleet which are going to be calculated as the ex-vessel price of the catch.

The conversion rate is determined comparing the total amount that is used as raw material and the final products that are obtained, while to determinate which proportion of this raw material is transformed in each fish meal type, export registrations are used.

Table A.6: Raw material v/s production in tons by year (Tons)

Year	2005	2006	2007	2008	2009	2010
Fish Oil	8,053	32,852	47,852	59,791	68,307	48,779
Fish Meal	147,338	173,520	179,400	247,268	257,565	212,941
Raw Material	723,529	826.035	812,793	1,182,105	1,288,766	964,104

Source: Subpesca Databases

Table A.7: Fish meal exportation in tons by year

Year	2005	2006	2007	2008	2009	2010
Standard Fish Meal	71,629	35,087	83,439	98,477	98,217	27,941
Prime Fish Meal	283,555	176,182	154,237	171,617	213,253	83,392
Super prime Fish Meal	281,266	239,061	194,243	143,957	168,746	102,219

Source: Subpesca Databases

In order to get the parameters value, all of the data are divided by the catch during 2009.The following table shows a summary of the parameters for the mathematical model.

Table A.8: Parameters for the model

Item	Value by ton (CLP)
Artisanal fleet	
Employment fe_1	0.000849
Operational cost	$ 12,723
Wages	$ 26,926
Capture variable cost cvc_1	$ 39,649
Ex-vessel price ep_1	$ 67,315
Industrial fleet	
Employment fe_2	0.000478
Capture variable cost cvc_2	$ 16,302
Ex-vessel price ep_2	$ 71,267
Final products prices	
Standard fish meal p_2	$ 565,209
Prime fish meal p_3	$ 568,007
Super prime fish meal p_4	$ 643,554
Fish oil p_1	$ 355,914
Destination of raw material by product	
Standard fish meal $Prop_{2-2}$	0.2
Prime fish meal $Prop_{2-3}$	0.45
Super prime fish meal $Prop_{2-4}$	0.35
Standard fish meal $Prop_{1-2}$	1
Technical transformation coefficient by product	
Standard fish meal $coef_2$	0.2
Prime fish meal $coef_3$	0.2
Super prime fish meal $coef_4$	0.2
Fish oil $coef_1$	0.05
Processing industry employment	
pe_j	0.004838
Production cost (fish meal) pcv_j	
Processing cost	$ 67,154
Storage, transport and any other costs	$ 72,471
Extreme values for TAC	
TAC_{min}	1,029,000
TAC_{max}	1,543,500

*Values are expressed in 2009 Chilean pesos

Table A.9: Trade offs between the objective functions

τ_1	$\triangle\ TIF$	$\triangle\ TE$	$\triangle\ CS$	MRS_{TE-TIF} Million CLP /Awus	MRS_{CS-TIF} Million CLP /1 equity unit	MRS_{CS-TE} Awus /1 equity unit
1	-	-	-	-	-	-
0.975	935.199	-11.93	0.0182	78.39	-51,519	657.2
0.95	935.199	-11.93	0.0186	78.39	-50,247	641.0
0.925	935.199	-11.93	0.0191	78.39	-49,007	625.2
0.9	935.199	-11.93	0.0196	78.39	-47,797	609.7
0.875	935.199	-11.93	0.0201	78.39	-46,617	594.7
0.85	935.199	-11.93	0.0206	78.39	-45,466	580.0
0.825	935.199	-11.93	0.0211	78.39	-44,343	565.7
0.8	935.199	-11.93	0.0216	78.39	-43,248	551.7
0.775	935.199	-11.93	0.0222	78.39	-42,180	538.1
0.75	935.199	-11.93	0.0227	78.39	-41,139	524.8
0.725	935.199	-11.93	0.0233	78.39	-40,123	511.8
0.7	935.199	-11.93	0.0239	78.39	-39,133	499.2
0.675	935.199	-11.93	0.0245	78.39	-38,166	486.9
0.6674	284.301	-3.63	0.0076	78.39	-37,550	479.0
0.65	935.199	-11.93	-0.0097	78.39	96,628	-1,232.7
0.625	935.199	-11.93	-0.0243	78.39	38,542	-491.7
0.6	935.199	-11.93	-0.0237	78.39	39,518	-504.1
0.575	935.199	-11.93	-0.0231	78.39	40,518	-516.9
0.55	935.199	-11.93	-0.0225	78.39	41,544	-530.0
0.525	935.199	-11.93	-0.0220	78.39	42,596	-543.4
0.5	935.199	-11.93	-0.0214	78.39	43,674	-557.1
0.475	935.199	-11.93	-0.0209	78.39	44,780	-571.2
0.45	935.199	-11.93	-0.0204	78.39	45,913	-585.7
0.425	935.199	-11.93	-0.0199	78.39	47,076	-600.5
0.4	935.199	-11.93	-0.0194	78.39	48,267	-615.7
0.375	935.199	-11.93	-0.0189	78.39	49,489	-631.3
0.35	935.199	-11.93	-0.0184	78.39	50,742	-647.3
0.325	935.199	-11.93	-0.0180	78.39	52,027	-663.7
0.3	935.199	-11.93	-0.0175	78.39	53,344	-680.5
0.275	935.199	-11.93	-0.0171	78.39	54,694	-697.7
0.25	935.199	-11.93	-0.0167	78.39	56,079	-715.4
0.225	935.199	-11.93	-0.0163	78.39	57,498	-733.5
0.2	935.199	-11.93	-0.0159	78.39	58,954	-752.1
0.175	935.199	-11.93	-0.0155	78.39	60,446	-771.1
0.15	935.199	-11.93	-0.0151	78.39	61,977	-790.6
0.125	935.199	-11.93	-0.0147	78.39	63,546	-810.6
0.1	935.199	-11.93	-0.0144	78.39	65,154	-831.1
0.075	935.199	-11.93	-0.0140	78.39	66,804	-852.2
0.05	935.199	-11.93	-0.0137	78.39	68,495	-873.8
0.025	935.199	-11.93	-0.0133	78.39	70,229	-895.9
0.00	935.199	-11.93	-0.0130	78.39	72,007	-918.6

Source: Compiled by author

Table A.10: Trade offs between the objective functions when TAC is duplicated

τ_1	Δ TIF	Δ TE	Δ CS	MRS_{TE-TIF} Million CLP /Awus	MRS_{CS-TIF} Million CLP /1 equity unit	MRS_{CS-TE} Awus /1 equity unit
1	-	-	-	-	-	-
0.975	1870.3985	-23.8599	0.0182	78.39	-103,039	1,314.4
0.95	1870.3985	-23.8599	0.0186	78.39	-100,495	1,282.0
0.925	1870.3985	-23.8599	0.0191	78.39	-98,013	1,250.3
0.9	1870.3985	-23.8599	0.0196	78.39	-95,594	1,219.4
0.875	1870.3985	-23.8599	0.0201	78.39	-93,233	1,189.3
0.85	1870.3985	-23.8599	0.0206	78.39	-90,931	1,160.0
0.825	1870.3985	-23.8599	0.0211	78.39	-88,686	1,131.3
0.8	1870.3985	-23.8599	0.0216	78.39	-86,497	1,103.4
0.775	1870.3985	-23.8599	0.0222	78.39	-84,361	1,076.2
0.75	1870.3985	-23.8599	0.0227	78.39	-82,278	1,049.6
0.725	1870.3985	-23.8599	0.0233	78.39	-80,247	1,023.7
0.7	1870.3985	-23.8599	0.0239	78.39	-78,265	998.4
0.675	1870.3985	-23.8599	0.0245	78.39	-76,333	973.7
0.6674	568.6011	-7.2534	0.0076	78.39	-75,101	958.0
0.65	1870.3985	-23.8599	-0.0097	78.39	193,257	-2,465.3
0.625	1870.3985	-23.8599	-0.0243	78.39	77,085	-983.3
0.6	1870.3985	-23.8599	-0.0237	78.39	79,036	-1,008.2
0.575	1870.3985	-23.8599	-0.0231	78.39	81,037	-1,033.8
0.55	1870.3985	-23.8599	-0.0225	78.39	83,088	-1,059.9
0.525	1870.3985	-23.8599	-0.0220	78.39	85,192	-1,086.8
0.5	1870.3985	-23.8599	-0.0214	78.39	87,348	-1,114.3
0.475	1870.3985	-23.8599	-0.0209	78.39	89,560	-1,142.5
0.45	1870.3985	-23.8599	-0.0204	78.39	91,827	-1,171.4
0.425	1870.3985	-23.8599	-0.0199	78.39	94,151	-1,201.1
0.4	1870.3985	-23.8599	-0.0194	78.39	96,535	-1,231.5
0.375	1870.3985	-23.8599	-0.0189	78.39	98,979	-1,262.6
0.35	1870.3985	-23.8599	-0.0184	78.39	101,484	-1,294.6
0.325	1870.3985	-23.8599	-0.0180	78.39	104,053	-1,327.4
0.3	1870.3985	-23.8599	-0.0175	78.39	106,688	-1,361.0
0.275	1870.3985	-23.8599	-0.0171	78.39	109,388	-1,395.4
0.25	1870.3985	-23.8599	-0.0167	78.39	112,158	-1,430.8
0.225	1870.3985	-23.8599	-0.0163	78.39	114,997	-1,467.0
0.2	1870.3985	-23.8599	-0.0159	78.39	117,908	-1,504.1
0.175	1870.3985	-23.8599	-0.0155	78.39	120,893	-1,542.2
0.15	1870.3985	-23.8599	-0.0151	78.39	123,953	-1,581.2
0.125	1870.3985	-23.8599	-0.0147	78.39	127,091	-1,621.3
0.1	1870.3985	-23.8599	-0.0144	78.39	130,309	-1,662.3
0.075	1870.3985	-23.8599	-0.0140	78.39	133,607	-1,704.4
0.05	1870.3985	-23.8599	-0.0137	78.39	136,990	-1,747.5
0.025	1870.3985	-23.8599	-0.0133	78.39	140,457	-1,791.8
0.00	1870.3985	-23.8599	-0.0130	78.39	144,013	-1,837.1

Source: Compiled by author

A.2 Results

Table A.11: Profit function optimization results (using equity as constraint)

Maximum Profit	Lower bound for equity	τ_1	τ_2	Employment (awus)
$ 70,925	1.00000	0.6674	0.3326	2178
$ 71,576	0.98275	0.6500	0.3500	2170
$ 72,511	0.95849	0.6250	0.3750	2158
$ 73,446	0.93482	0.6000	0.4000	2146
$ 74,381	0.91174	0.5750	0.4250	2134
$ 75,317	0.88923	0.5500	0.4500	2122
$ 76,252	0.86727	0.5250	0.4750	2110
$ 77,187	0.84586	0.5000	0.5000	2098
$ 78,122	0.82498	0.4750	0.5250	2086
$ 79,057	0.80461	0.4500	0.5500	2074
$ 79,993	0.78474	0.4250	0.5750	2062
$ 80,928	0.76537	0.4000	0.6000	2050
$ 81,863	0.74647	0.3750	0.6250	2038
$ 82,798	0.72804	0.3500	0.6500	2026
$ 83,733	0.71006	0.3250	0.6750	2014
$ 84,669	0.69253	0.3000	0.7000	2003
$ 85,604	0.67543	0.2750	0.7250	1991
$ 86,539	0.65876	0.2500	0.7500	1979
$ 87,474	0.64249	0.2250	0.7750	1967
$ 88,409	0.62663	0.2000	0.8000	1955
$ 89,345	0.61116	0.1750	0.8250	1943
$ 90,280	0.59607	0.1500	0.8500	1931
$ 91,215	0.58135	0.1250	0.8750	1919
$ 92,150	0.56700	0.1000	0.9000	1907
$ 93,085	0.55300	0.0750	0.9250	1895
$ 94,021	0.53934	0.0500	0.9500	1883
$ 94,956	0.52603	0.0250	0.9750	1871
$ 95,891	0.51304	0.0000	1.0000	1859

Source: Compiled by author

Table A.12: Employment function optimization results (using equity as constraint)

Maximum Employment	Lower bound for equity	τ_1	τ_2	Profit (CLP$ million)
2178	1.0000	0.6674	0.3326	$ 70,925
2182	0.9924	0.6750	0.3250	$ 70,641
2193	0.9679	0.7000	0.3000	$ 69,705
2205	0.9440	0.7250	0.2750	$ 68,770
2217	0.9207	0.7500	0.2500	$ 67,835
2229	0.8980	0.7750	0.2250	$ 66,900
2241	0.8758	0.8000	0.2000	$ 65,965
2253	0.8542	0.8250	0.1750	$ 65,029
2265	0.8331	0.8500	0.1500	$ 64,094
2277	0.8125	0.8750	0.1250	$ 63,159
2289	0.7925	0.9000	0.1000	$ 62,224
2301	0.7729	0.9250	0.0750	$ 61,289
2313	0.7538	0.9500	0.0500	$ 60,353
2325	0.7352	0.9750	0.0250	$ 59,418
2337	0.7171	1.0000	0.0000	$ 58,483

Source: Compiled by author

Table A.13: Profit function optimization results (using employment as constraint)

Profit (CLP$ million)	Upper bound for employment	τ_1	τ_2	Equity
$ 58,483	2,337	1.00	0.00	0.71706
$ 60,353	2,313	0.95	0.05	0.75382
$ 62,224	2,289	0.90	0.10	0.79247
$ 64,094	2,265	0.85	0.15	0.83310
$ 65,965	2,241	0.80	0.20	0.87582
$ 67,835	2,217	0.75	0.25	0.92072
$ 69,705	2,193	0.70	0.30	0.96793
$ 71,576	2,170	0.65	0.35	0.98275
$ 73,446	2,146	0.60	0.40	0.93482
$ 75,317	2,122	0.55	0.45	0.88923
$ 77,187	2,098	0.50	0.50	0.84586
$ 79,057	2,074	0.45	0.55	0.80461
$ 80,928	2,050	0.40	0.60	0.76537
$ 82,798	2,026	0.35	0.65	0.72804
$ 84,669	2,003	0.30	0.70	0.69253
$ 86,539	1,979	0.25	0.75	0.65876
$ 88,409	1,955	0.20	0.80	0.62663
$ 90,280	1,931	0.15	0.85	0.59607
$ 92,150	1,907	0.10	0.90	0.56700
$ 94,021	1,883	0.05	0.95	0.53934
$ 95,891	1,859	0.00	1.00	0.51304

Source: Compiled by author