Downward Adjustments in a Cyclical Environment: The Case of Chilean Pelagic Fisheries[1]

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Abstract

Often the scale of production of many industrial fisheries in the world shows rigidity vis à vis declines in fish abundance, which on occasions has generated fishing collapse. This paper studies the two fisheries with the greatest volume of landings in Chile, and which are also characterized by strong variability in their abundance. Production-side aspects that affect the incentives to adjust towards lower fishing efforts are analyzed. To do so, production functions for industrial fleets at each fishery are estimated by resorting to panel data. Two main results are obtained. First, we confirm the empirical relevance of Translog harvest technologies. This contradicts a frequent practice in bioeconomic models, which considers harvest-inputs elasticities as being constant and independent from the *sca*le of production. Second, a set of production-side effects are identified that weaken the incentives to adjust towards lower fishing efforts: increasing returns in the use of variable inputs, which are also strengthened by external economies associated to the aggregate searching effort for fish, and catch yields sensitive to changes in abundance, but where the strength of this effect decreases as abundance declines.

Key words: Chilean pelagic fisheries; harvest functions; panel estimation; fishing cycles.
JEL classification numbers: Q22, C33, L7

1. Introduction

This paper offers an empirical analysis of production functions in the two most important areas of pelagic fishing in Chile: the Northern and the Central-Southern fishing zones (Figure 1). These fisheries are the ones that generate the greatest volume of fish landings in Chile. The central purpose is to analyze production-side aspects that affect the incentives to adjust the fishing effort, above all to face scarcer fish stocks. If there are costs associated to adjusting to a declining scale of production, downward cycles of fish abundance could derive in situations of fishing collapse. If no significant adjustment costs exist, variability in abundance could imply optimal exploitation of a cyclical type.

In the theoretical literature on these subjects there are two production-side aspects that stand out. One issue is how sensitive fishing costs are in the face of variations in fish abundance. The other being the impact that the presence of increasing harvest returns has on fishing efforts. Clark (1971) provides a classical argument on the possibility of facing fishing collapse when the fishing cost is insensitive to changes in fish abundance. As a reaction to these arguments, a series of papers have discussed the possibility that costs which are sufficiently sensitive to changes in abundance could manage to avoid situations of collapse. An important assumption in this line of models is that there are no costs associated to adjusting the scale of production.

Based on the latter assumption, Beddington et al. (1975) argue that the presence of increasing fishing returns, above all at relatively low levels of fish abundance, could well be another incentive to avoid situations of fishing collapse. In Beddington et al.'s model, the productive optimum implies cyclical production. Following this same line of analysis, Lewis and Schmalensee (1979, 1982) consider the existence of costs associated to the adjustment of the scale of production. They argue that the higher these costs are, the greater the risk that increasing returns in fishing could derive in fishing collapse. Dawid and Kopel (1997) and Liski et al. (2001) also present models that incorporate explicit costs to productive adjustment and within this context they discuss the possible optimality of cyclical production.

The two fisheries analyzed in this paper are interesting cases for studying empirical evidence on the previous theoretical arguments. On the one hand, they are fisheries which exploit species of small pelagic fish (e.g. sardine, anchovy, jack mackerel), which are characterized by facing strong and recurrent cycles of fish abundance (in our case, influenced by the environmental phenomenon known as *El Niño*). On the other hand, and in relative terms to other fish species, pelagic fish stocks are usually characterized for providing high catch yields.[2] In the two fisheries analyzed this characteristic is reinforced by the high fishing productivity that is associated to the Humboldt current. Given this particular combination of characteristics, different fisheries of small pelagic fish in the world have experienced problems of fishing collapse. Examples in the XXth century are the sardine fisheries in Japan at the beginnings of the 1940's, the sardine fishery in California a decade later, the herring population in the North Sea at the end of the 1960's and beginnings of the 1970's, and the collapse of the anchovy fishery in Peru during the period 1972-73 (Peña-Torres, 1996).

With respect to sources of empirical evidence on these subjects, there are some studies that consider econometric estimations of production functions for pelagic–type fisheries in the Northern hemisphere, and in which productive aspects of the type we are interested in this paper are studied. For example, Bjorndal (1987, 1989) and Bjorndal and Conrad (1987), when they analyze a herring fishery in the North Sea, find signals of *increasing* fishing returns associated to increases in the number of vessels in operation.[3] Bjorndal et al. (1993) obtain results in this same direction, when they study the Norwegian fleet that operates in the seal fishery facing the peninsula of Newfoundland-El Labrador. On the other hand, Opsomer and Conrad (1994), when studying the anchovy fishery in California, obtain estimation results that suggest *constant* fishing returns (in this case, using fishing days as a proxy of fishing effort).

Related to the sensitivity of fishing costs in the face of changes in fish abundance, when we perform estimations of production functions, a parameter of interest is the estimated value for the harvest-fish-stock elasticity. If the estimated value for this elasticity is positive (and statistically significant), a greater value of this elasticity implies that average fishing costs will be more sensitive (*i*.e., increasing) in the face of declining fish stocks, acting as a brake to continued expansions in the scale of production. In estimations made for pelagic-type fisheries, results with positive values are predominant for this elasticity, though they are usually lower than the unit value. This is the case of the results obtained for the herring fishery in the North Sea (Bjorndal and Conrad, 1987)[4], as well as for the anchovy fishery in California (Opsomer and Conrad, 1994). Less conclusive results are obtained in Bjorndal et al. (1993).

This study should also provide additional information with respect to a well-known biological hypothesis, related to the risks of fishing collapse in pelagic-type fisheries. Marine biologists have stated that in pelagic fisheries there is a trend to observe a negative correlation between fish abundance and the *catchability coefficient* (Csirke 1988).[5] This implies that mean harvest yields (per unit of fishing effort) are not a good predictor of changes occurred in the fish abundance. The hypothesis is that when abundance falls, the fish stock tends to reduce the range of its feeding and breeding areas, with concurrent decreases in the number of schools, though the average size of each remains constant. That is, the stock reduces the range of its spatial distribution while simultaneously increasing its density. Some studies have stated that this could result in a relation of total independence between harvest and fish abundance (e.g. Bjorndal 1988, 1989). Our estimations of harvest-abundance elasticities will provide additional information on this hypothesis.

The authors are not aware of previous studies of this type on pelagic fisheries in the Southern Hemisphere. In our case, the analysis of the evidence is enriched by the comparisons that can be made between the two fisheries studied. During the sampling period, these two fisheries face different cycles of fish abundance and fishing productivity. Northern Chile presents a cycle with parallel drops in fish abundance and in fishing yields. By contrast, in the Central-Southern zone fishing yields grow uninterruptedly, despite the fact that the abundance of the main fish stocks begins a declining cycle during the sampling period.

Our analysis considers panel models, using algorithms of fixed and random effects, to estimate harvest functions for the industrial fleets that operated at each fishery during the period 1985-95. In the Northern zone the fleet analyzed includes a total of 250 vessels; in the Central-Southern zone 209 vessels are studied. In this paper we use estimation methods which, while being common and consistent to both fisheries, are more general than those considered in prior studies on these fisheries (see Peña-Torres and Basch, 2000; Peña-Torres et al. 2003).

The following section describes the two fisheries under study. Section 3 presents the production model to be estimated, discussing the variables and data used. Section 4 analyzes econometric aspects which condition the validity of the estimation results. Section 5 discusses the main results obtained, including the empirical validation of the Translog functional form, and the estimated values for the different harvest-input elasticities, calculating point estimates according to different valuation criteria. Section 6 presents conclusions. Appendices 1-4 provide complementary information.

2. Description of the Fisheries

Pelagic fishing in Chile is developed mainly in the Northern and Central-Southern zones. In the year 2000, pelagic harvest in both zones represented 92% of industrial fish landings in Chile (39% in the Northern zone and 53% in the Central-Southern zone).[6] Pelagic fishing is the main raw material of the reduction industry devoted to fishmeal and fish oil production, both commodities with a high degree of substitution on the demand side. In the years 2000 and 2001, the value of Chilean export products based on pelagic fish was in the order of US$ 320 mill/year. The two zones analyzed correspond to independent fisheries.[7]

In Northern Chile the main species are anchovies and Pacific sardine, with the jack mackerel having a scant participation. In this zone since the beginning of the 1970s, the Pacific sardine became the dominant landed species, reaching harvest peaks during 1983-85. In the next decade, sardine harvests experienced systematic reductions, and the anchovy in turn became the new dominant species. On the other hand, in the Central-Southern fishery the main harvested species were traditionally the anchovy and sardine. However, since the beginnings of the 1980s the jack mackerel becomes the dominant species. In the decade to be studied, the participation of the jack mackerel exceeds 88% of total industrial landings in the Central-Southern zone.[8]

The industrial fleets operating at both fisheries lack species-specialized vessels. The reason lies in a strategy for diversifying productive risk. Multi-species vessels contribute to reduce the risk connected to the cycles of one species in particular (Lipton and Strand, 1989). An additional reason is that the price of the final product does not differ significantly according to the pelagic species used as raw material. In this industry, and during the period under analysis, to maximize the volume of landings, independently from the particular pelagic species that form a part of it, has played a key role in the private profitability of the business.

In Northern Chile the fishery is conducted mainly as coastline fishing. In the Central-Southern fishery, since the beginnings of the 1990s, the proportion of fishing effort conducted beyond 60-100 miles from the coast has increased. Initially, this evolution was led by vessels in the range of 550-800 m^3 of hold capacity. Nowadays, a part of the industrial fleet, above all vessels over 800-900 m^3 of capacity, carries out part of its fishing efforts beyond 200 miles from the coast.

The two fisheries under scrutiny have experienced different time based dynamics over the last two decades. On the one hand, Northern Chile experienced a sustained increase in landings as from the second half of the 1970s, until it reached peaks of 3 – 3.3 million tons in 1985-86 (Graph 1). This was associated with a cycle of increasing abundance of sardine stocks, which began to revert since the middle of the 1980s (Appendix 1B). In a parallel manner, the abundance and landings of anchovy began an expansive cycle[9], which lasts up to the end of our sampling period (Appendix 1C).

The decline in the abundance of sardine stocks, added to the concurrent effects on landings in Northern Chile (evident as from 1986), unleashed additional regulations on the access to this fishery. In spite of this, during the 1990s the decline in harvest yields continued. The landings in 1994-95 were equivalent to 55-65% of the levels in effect a decade before. Ultimately, towards the end of the 1990s this evolution derives in a strong productive adjustment in this fishery: the companies begin significant efforts of operational rationalization, reducing the number of vessels in operation, as well as the labor hired in fleets and processing plants; and all this, parallel to a process of consolidation via mergers and buy-outs of companies in the sector.

Graph 1 and 2

On the other hand, the Central-Southern fishery began the decade of the 1980s with an investment boom, both in extractive as well as processing capacity. This occurs under free access conditions, which prevail from 1978 through 1986, period in which landings increase significantly. Later on, access regulations attempt to 'freeze' the aggregate hold capacity of the industrial fleet existing in the mid 1980s. However, legal voids enable the industry to continue expanding the fishing capacity and with it the landings. This process is also reinforced by expectations of regulatory change (Peña-Torres, 1997).[10] Thus, during 1985-95 the number of industrial vessels increases by six times, while the aggregate hold capacity increases by four times (Table 1). This coincides with an increasing participation of vessels of larger tonnage and greater maneuverability.[11] During the decade studied, the aggregate annual fishing effort (proxied by the variable annual haul; Table 1) increases 6.5 times. This expansion in the scale of operation generates a sustained growth in harvests, until reaching peaks of 4 - 4.5 million tons/year in 1994 and 1995.

The Central-Southern fishery presents an upward trend in landings until the middle of the 1990s, even though the abundance of jack mackerel had been decreasing since the middle of the 1980s (Graph 2). However, in 1995 acute falls begin in the yearly harvest. This process is aggravated with the arrival in 1997 of an *El Niño* phenomenon of great intensity,[12] in the face of which temporary biological closures are implemented. Starting in 1998, the use of biological closures begins to be complemented '*de facto*' by harvest quotas for each industrial vessel. At present, the harvest levels for the three main species correspond to less than half of the peak recorded in 1994-1995; in the case of the jack mackerel the fall is even greater. As a consequence of incentives created by an important reform to the Chilean Fisheries Law at the beginning of the year 2002, nowadays a significant operational adjustment is observed in this fishery, not only in terms of reductions in the number of vessels in operation, but also in the fishing capacity which they displace (Peña-Torres, 2002).

Table 1

3. Theoretical Model, Data and Variables

The model corresponds to a production function that characterizes yearly harvests at the vessel level, with respect to different productive inputs. The harvest technology is modeled by a Translog function, specific to each fishery, with the purpose of verifying if the value of harvest-input elasticities is sensitive to the scale of extraction (Peña-Torres and Basch, 2000). The model to be estimated is:

$$c_{it} = \beta_{0i} + \sum_j \beta_j x_{jit} + \sum_j \sum_k \beta_{jk} x_{jit} x_{kit} + \varepsilon_{it} \quad (1)$$

Sub-indices (*i, t*) refer to the vessel i (i = 1,...,N) and the year t (t = 1985,...,1995). Sub-indices (*k,j)* denote explanatory variables. The variables considered for each fishery in question are:

c_{it} = natural log of yearly harvest (total species) in tons, for ship i in year t.
x_1 : b_t = natural log of the aggregate biomass variable, lagged by one year.
x_2 : a_t = natural log of yearly haul of the industrial fleet in year t.
x_3 : h_{it} = natural log of the hold capacity (in m^3) of vessel i in year t.[13]
x_4 : e_{it} = natural log of total fishing hours of vessel i in year t.
x_5 : f_{it} = natural log of fishing effectiveness of vessel i in year t.
x_6 : g_{it} = natural log of age (measured in years) of vessel i in year t.
x_7 : T = trend variable (T=1 for 1985,..., T=11 for 1995).

To simplify, hereinafter the following conventions are used: small letters denote the natural logarithm of the corresponding variable (e.g., x= ln X); and the time sub-index t is eliminated. The meaning of the variables considered is defined and explained below.

The data were obtained from the Chilean Fisheries Research Institute (*IFOP*) and correspond to the Northern and Southern-Central pelagic fisheries. The information is organized by fishery, at vessel level and for each year of the period 1985-1995, for the total industrial fleet in each zone. Per vessel data include: (i) landings of the species harvested (measured in tons), (ii) total hours of operation at sea, (iii) hours of operation at sea, on trips with fishing success, iv) hold capacity of the vessels (measured in m^3) and (v) year of construction of the vessel. We also have annual biomass estimations (*proxy* of fish abundance, measured in tons) carried out by *IFOP* for the three main species harvested at each fishery.

The harvest data by vessel (C_{it}) consider the total tonnage landed in each year t, including total species harvested. On the basis of biomass estimations (average values for each year) carried out by *IFOP* for the three main species at the fisheries under study, the *exploitable stock* for each species is defined as the biomass of all cohorts above and including the recruitment age.[14] This definition is related to minimum fish-size regulations on the catch permitted. The biomass estimations made by *IFOP* are based on the methodology known as virtual population analysis (Gulland, 1988).[15] Given that the harvest data refers to the total of species landed, the biomass variable has been defined, denoted by B_t for year t, as a proxy of yearly aggregate abundance of all pelagic stocks, summing the tons of exploitable biomass of each one of the three main pelagic species. To this, a residual calculation on the (minority) biomass of other species harvested is added. The *proxy* variable for aggregate biomass seeks to control for the sensitivity of the harvest in the face of changes in the aggregate availability of fish stocks.

In order to approximate the use of variable inputs, the fishing effort variable of each vessel (E_{it}) was defined, equivalent to the yearly hours of operation at sea of vessel i in year t, whether it has succeeded or not in obtaining harvest in its trips. Hence E_{it} includes the actual hours of fishing as well as those in which fish search maneuvers were performed. On the other hand, the hold capacity of each vessel (H_{it}) is used as a *proxy* variable to control for fixed factors that have a bearing on fishing yields. This assumes that the hold capacity of each vessel is correlated positively with other fixed factors that have an influence on its fishing yield (e.g., engine power, use of sonar). Additionally, the variable haul (A_t) is defined at the level of the industrial fleet as a whole, where $A_t = \sum_i H_{it} * E_{it}$, $\forall$i that has operated in year t, seeking to control for possible external effects to the vessel, associated to the fishing effort of the total industrial fleet.

Besides, the variable fishing effectiveness (F_{it}) is defined as the ratio between the yearly hours on trips that have had fishing success, and the total of yearly hours of operation at sea that each vessel i makes in year t. This variable attempts to control for differences in harvest yields associated to vessel-specific factors and which could also vary over time (e.g., the fishing experience of the skipper and crew). On the other hand, the variable age (G_{it}) has been defined as the difference between year t and the year when the boat was built. The variable G_{it} seeks to control for possible effects of technological obsolescence. If there have been technological improvements in harvest operations or in inputs used, the expected effect would be a negative correlation between G_{it} and C_{it}. However, G_{it} could also be related to accumulative learning effects in fishing activities, in which case the sign of the net impact could be positive.

Other variables considered seek to control for temporal *shocks*. Three *dummy* variables (D_t) have been included: one for 1987, which controls for the presence of *El Niño* phenomenon that year (of moderate intensity), and two others for 1988 and 1989, years related to expectations of regulatory change (Peña Torres, 2002). A trend variable (T=1, 2, …,11) has also been included seeking to control for temporal changes in trends.

The estimations were made separating the vessels in size categories, defined according to hold capacity.[16] The chosen subdivision allows to control partially for differences in the maneuverability of different sized vessels. Though a significant part of the industrial fleet has a potential to fish beyond the first 100 miles, in actual practice the larger vessels are those having greater and more effective fishing autonomy. Thus, in the Central-Southern zone three panels have been defined: PS1 (80-300 m^3), PS2 (301-800 m^3) and PS3 (801 and more m^3). In the Northern zone two panels have been considered, namely: PN1 (80-300 m^3) and PN2 (301- 800 m^3).

The samples for both fisheries correspond to unbalanced panels, a phenomenon known in the literature as *attrition* (Mátyás and Sevestre, 1996). In our data, this phenomenon is not very significant: on average PN1 and PN2 have 8 and 7 observations/vessel, respectively, whereas PS1 and PS2 have correspondingly 7.2 and 7.3 observations/vessel. The only panel with a more significant *attrition* is PS3; on average it has 3.3 observations/vessel. Table 2 shows the number of vessels in our estimation sample, according to the vessels that operated each year.

Table 2

4. Econometric information

Two estimation algorithms are used for each fishery: a fixed effect model and another with random effects. The model structure is:

$$Y_{it} = \alpha + X_{it}\beta + \varepsilon_{it} \quad (2)$$
$$\varepsilon_{it} = u_i + \nu_{it}$$

In the two estimation algorithms used, the terms ν_{it} are assumed to be of type i.i.d. The main difference lies in the treatment and interpretation which the terms $\alpha_i=(\alpha+u_i)$ receive. Simplifying, let it be assumed that these terms correspond to variables that (i) control for vessel-specific, (ii) are invariant in time and (iii) are not explicitly contained in the matrix X. Examples of these variables can be the engine power, the fish search technology, or other factors which imply systematic differences in productivity among vessels.

The properties of the estimators obtained according to one or the other algorithm will differ depending on whether $E[X_{it}'\alpha_i]$ is equal to or different from zero. If the first condition is fulfilled, both algorithms generate consistent estimators, even though algorithms of random effects will generate more efficient estimators. If the second condition holds, fixed effects algorithms will continue generating consistent estimators while random effects estimates will be inconsistent (Johnston and DiNardo, 1997).

In this paper, the random-effects algorithm uses generalized least squares. In the case of fixed-effects we use the standard algorithm which resorts to dicothomic (vessel-specific) variables to control for non observed variables for each vessel.

Exogeneity

Seeking to maintain simplicity and tractability, it is a frequent practice in estimating production functions to consider explanatory variables that represent the choice of productive inputs as exogenous. This assumption is supported by the classical proof of consistent estimators proposed by Zellner, Kmenta and Drèze (1966).[17]

However, the above reasoning cannot be applied *strictu sensu* to the biomass variable, given that it is beyond human control. Biomass levels could be affected by the contemporary harvest of the fleet as a whole. Notwithstanding, in order to test this hypothesis, reliable information for the biological growth function of the species under study is necessary.[18] However, to perform properly this testing goes beyond this paper's scope. To overcome this potential problem, a *proxy* variable for biomass is used: its one-yearly lagged value. This should lessen a potential problem of endogeneity (see Peña and Basch, 2000).

Despite what has been stated above, Hausman-type exogeneity tests were conducted for the variables whose exogenous character is dubious, using the modal panels for each fishery (PN1 and PS2). The results obtained are consistent with the theoretical argument posed by Zellner *et al*.[19]

According to our tests, contemporaneous fishing effort at the vessel level can be considered as an exogenous variable in our estimation exercises. There are two main reasons that may help explain this result. First, in both fisheries and through the entire sampling period, to maximize the volume of landings has played a key role in the private profitability of the fish reduction industry. Hence, vessels operate accordingly. Second, in both fisheries the only binding constraints on fishing effort are biological closures and the presence of bad weather. During the sampling period none of the two fisheries had catch quotas. Thus the constraints on fishing effort can reasonably be considered as being exogenous, and hence fishing effort itself, with respect to vessel's harvest.[20]

Stationarity

It is advisable to verify if the explanatory variables of the model are stationary, so as to avoid problems associated to spurious regressions (Granger and Newbold, 1974; Banerjee et al., 1993). The traditional unit root tests (Dickey and Fuller, 1979) have been developed as a consistent methodology to elucidate this problem, though strictly speaking they are applicable only to time series and not to panel data. In the latter case, there is not a general consensus as to which methodology is more suitable. In this paper, we have relied on the methodology proposed by Levin and Lin, which has received considerable backing by the specialized literature. (Maddala and Kim, 1998).

Appendix 2 shows the results of this test. The variables tested (harvest, fishing effort and effectiveness) showed to be stationary in trend (with a clear statistical significance), besides all of them being stochastically stationary.[21] This result supports the inclusion of a trend term as an additional regressor, which aims to control for temporal trend changes that might have had an influence on the fleet's harvest during the sampling period.

Estimation Procedure

The panels within each one of the fisheries were estimated separately, using the White's formalism to correct for possible sources of heteroscedasticity at the vessel level (White, 1980). In addition, for each panel, a parsimonious Translog model was obtained through a sequential use of Wald tests, eliminating all coefficients which were not jointly significant (Davidson and MacKinnon, 1981). The procedure of successive elimination of variables was done independently for both the fixed effects cases as for that of random effects. Final results (parsimonious models) are reported in Appendices 4 and 5.[22]

To test the relative validity between the fixed and random effects models, and to verify which model fits the data better, a Hausman test (Hausman and Taylor, 1981) was resorted to. These tests are applied by comparing equivalent parsimonious models, *i.e.,* having the same regressors, for the two estimation algorithms (Appendix 3). For all panels the validity of the random effects model is rejected (e.g., at 5%), except for the case of PS3. However, PS3 shows an attrition effect that is more significant than in the other panels, casting doubt on the statistical relevance for this case. The results analyzed below consider the parsimonious models under the fixed effects models, save the case of PS3 where the random effects algorithm can not be rejected.

5. Empirical Results

The empirical validation of the Translog function for the two fisheries analyzed robustly confirm prior results (Peña-Torres and Basch, 2000, Peña-Torres et al., 2003). The Translog technology implies that changes in the scale of input use, or in fish abundance for that matter, do not affect fishing yields proportionally. On the contrary, the degree and sign of the impact are conditioned by the scale of fishing. This result is to be understood in the light of a well-known characteristic of small pelagic fish, *i*.e., that these species are subject to significant variability in their abundance, with cycles tending to alternate in scales of decades (Llych-Belda et al. 1992; Csirke and Gumy 1996).

In what follows, the analysis will be focused on the estimated values for different harvest-inputs elasticities. Table 3 reports values for four elasticities, calculated on the basis of parsimonious estimations obtained with the fixed effects methodology and using the sampling averages (period 1985-95) for all the relevant variables. For the PS3 panel values are reported according to both estimation algorithms.

Graphs 3-6 report estimated values for these same elasticities, calculated on the basis of alternative valuation criteria. On the one hand, considering the average values, in each year, for all the relevant variables in each elasticity. On the other hand, *ceteris paribus* values calculated using the sampling average (1985-95) for all the relevant variables, except the input variable itself, for which the average in each year of the sample is considered.

Table 3

Harvest-Biomass Elasticity

Considering average values for all the sampling period (1985-95), positive values are obtained in all panels studied (though not statistically different from zero in the case of PS3 under random effects). Additionally, a greater vessel size tends to be associated with lower values of this elasticity. On the other hand, and considering the modal size PS2 in the Southern zone, similar vessels in the North present a greater sensitivity to changes in fish abundance.

These results endorse the hypothesis that vessels with greater mobility (on average those of greater size) obtain harvest yields that tend to be less sensitive to changes in fish abundance. A greater mobility increases the search capacity in different areas of the sea, which could help keep track of spatial-migratory changes.

In the Northern Zone, the average-yearly values of this elasticity tend to fall as years go by (Graph 3-1A). This occurs together with a declining trend in the abundance of the main species under exploitation. This indication of a positive correlation between fish abundance and the values of this elasticity is observed even more explicitly when calculating *ceteris paribus* values. On the other hand, the Northern zone data in Graph 3 ratify the greater sensitivity of the harvest in smaller vessels in the face of changes in fish abundance.

The results for the Central-Southern zone confirm the positive correlation between fish abundance and the value of this elasticity (see 1987 and thereafter). Note that since 1986 and until the end of the sampling period, a declining trend has been observed in the abundance of the dominant species (Graph 2). In addition, when comparing the panel PS1 versus PS2 and PS3, a trend to greater vessel's mobility once again attenuates the strength of this correlation. Only for PS3, no positive sign is obtained for this correlation.

Summing up, the harvest yields show to be sensitive to changes in fish abundance. However, the strength of this sensitivity decreases as fish abundance diminishes. The latter effect could be associated with increases in the density of the fish schools.[23]

A positive correlation between fish abundance and the value of this elasticity has implications of interest. First, as the fish stock becomes less abundant, the incentives to reduce the fishing effort are weakened, because the penalty through a fall in the marginal harvest is diminished. Second, as the fish stock becomes scarcer, an increasing exit of lower sized vessels should be expected. At the two fisheries studied, this second implication is clearly ascertained in the operational adjustments that were in turn implemented, after a greater scarcity of the fish stocks under exploitation in each zone became evident.

Graph 3

Harvest Effort Elasticity

In the set of values calculated for this elasticity, a predominance of values higher than the unit is obtained. The only exception is panel PN1[24] (see Table 3 and Graph 4). This predominance is consistent with prior results, obtained for both fisheries under less general estimation contexts than the current one (see Peña-Torres and Basch 2000; Peña-Torres et al. 2003). This seems to be hinting at the existence of economies of scale in the use of the variable inputs at this fishery.

A related result, again valid at both fishing zones, is that the larger vessels are associated with a greater level of economies of scale. This is consistent with the processes of fleet substitution observed at both fisheries, which have favored to an increasing extent the predominance of larger vessels (with a greater intensity in the Central-Southern zone). Following this line of interpretation, declining values for this elasticity could be a signal of a gradual exhaustion of these *eco*nomies of scale, as levels of fishing effort increase and the fishing potential in each zone declines. Note that this type of declining trends is obtained for panels PN2 and PS3. These correspond to the larger sized vessel categories where a large proportion of new vessels entered the fisheries during the sampling period.

On the other hand, economies of scale in the use of variable inputs are observed with greater strength in the Central-Southern fishery. It seems likely that this differential between zones is associated with the different cycles of fish abundance and fishing productivity which both fisheries experienced during 1985-95. In the North, the decade studied consistently involves a declining trend in the productive potential of that fishery (Graph 1). Consistently, the aggregate fishing effort in this zone does not show any signals of continuing with its previous expansion. In the Southern fishing grounds, a falling fishing productivity cycle only begins when our sampling period finishes (Graph 2). Thus, fishing efforts repeatedly increase during 1985-95.

With respect to self-incentives to reduce the fishing effort when fish stocks become scantier, our results imply important ranges of drops in fish abundance in which the harvest-effort elasticity continues showing values above the unit. The combination of incentives deriving from this result and from the fact that harvest-biomass elasticity values decline as the scarcity of fish stocks increases, undoubtedly support the use of precautionary criteria when defining regulatory measures (for instance, fishing quotas) for this activity.

Graph 4

Harvest-Haul Elasticity

This elasticity is an indicator of the possible effects that aggregate fishing effort has on fishing yields at the vessel level. For a better understanding of the dynamics summarized in the average values of this elasticity for the period 1985-95 (Table 3), our analysis concentrates on the results described in Graph 5.

Our results show a set of similar effects for the different groups of vessels at both fisheries. First, and assuming all variables other than industrial haul constant (ceteris paribus elasticities), in all panels a positive correlation is obtained between the value of this elasticity and the level of industrial haul. Indeed, increases in the aggregate fishing effort generate externality effects at the vessel level, initially with a negative sign (at the lower levels of the observed range of yearly haul) and afterwards with a positive sign, as higher haul levels are attained.[25] In both fisheries this change of sign occurs at haul levels fluctuating between 6.6 (in the North) up to 7.1-8.1 (Center-Southern area) millions of m^3-days/year of hauled hold capacity. To understand better this magnitude: suppose we had a fleet made up only by vessels with 1000 m^3 of hold capacity, each one operating at 200 days/year (i.e., close to the average annual days of fishing operations of PS3-type vessels, during the period 1985-95); then the previous range of annual haul values would correspond to what is hauled by a fleet of 33 – 40 vessels of this type.

Therefore, according to our *ceteris paribus* estimations, and for haul levels higher than the previous range, at both fisheries positive externalities would begin to operate on the individual harvest. In previous papers (Peña-Torres et al. 2003) we have argued that this result may be a reflection of external search economies, resulting from collective efforts to locate schools of interest.[26] Another robust result is that the strength of this externality effect tends to correlate inversely with the vessel's size. Smaller vessels would benefit in a greater proportion from positive search externalities. Results in the same direction were reported for the Northern fishery in Peña-Torres and Basch (2000).

Graph 5

On the other hand, fish abundance systematically presents, in both fisheries and in all panels, a negative correlation with the value of this elasticity. Thus, scarcer fish stocks increase the likelihood that this externality effect has a positive sign.

However, Graph 5.1 reports falling trends in the value of this elasticity, at both fisheries, when we calculate it using the average at each year for the relevant variables. This occurs despite that at both zones fish abundance tends to decline during the sampling period. There are two effects that help to account for this result. First and more importantly, vessel's hold capacity is negatively correlated with the estimated value of this elasticity. Indeed, for smaller vessels this externality effect is estimated with greater strength. Notice that, again at both fisheries, vessels' average size (measured by hold capacity) increases during the sampling period. Secondly, in the North the variable 'fishing effectiveness' is correlated negatively with the value of the haul elasticity; and average fishing effectiveness in this zone falls throughout the period 1985-95.

Harvest-Age Elasticity

Only in the Central-Southern fishery the vessel's age attains statistical significance as an explanatory factor of the harvest.[27] In this zone, the most noticeable result is the difference obtained between PS1 and the other panels, with respect to the sign and magnitude of this elasticity. Only for the PS1 panel positive values are obtained, and these with a greater absolute value than in PS2 and PS3.

A set of arguments may help explain this divergence. First, a negative sign for this elasticity could reflect the use of newer and more effective fishing technologies, associated on average to the operation of newer vessels. Notice that both PS2 and PS3 are panels in which there occurred a net entry of newer vessels, whereas in PS1 a net exit of vessels did occur (Table 2). Consistently, the valid ranges of age for remaining vessels in the panel PS1 are higher than those relevant for PS2 and PS3 (see Graph 6.2).

Graph 6

Second, we could conjecture that in the panel where a net exit of vessels was observed (PS1), there most likely occurred a more exhaustive process of selection and discard, which would have favored the vessels with greater fishing efficiency in that group. Thus, the surviving vessels would probably have idiosyncratic productive advantages, some of them possibly associated to accumulated fishing experience. In this case, older vessels could well show better harvest yields. On this same train of thought, in the panels where there did not occur such a severe selection process (PS2 and PS3), and where by contrast new vessels entered the fishery (in all likelihood closer to the technological frontier), it is reasonable to expect that older vessels should obtain lower fishing yields, as an outcome of possible technological obsolescence.

Finally, reductions in biomass and increases in industrial haul tend to expand the differential (in favor of the PS1 group) in the values resulting for this elasticity (see Appendix 5). A possible interpretation is that the strength of eventual advantages associated with a greater fishing experience could be amplified (all the rest being constant) in periods of greater fish scarcity.

6. Final Considerations

The fisheries studied provide new empirical evidence on production-side disincentives to adjust towards a declining scale of production. This topic is particularly relevant at both fisheries, given the strong and recurrent cycles of fish abundance that they face together with high fishing yields. We do not know prior studies of the type developed here that have been applied to other fisheries facing abundance cycles in the Southern Hemisphere, where there exist important fishing areas at a world level.

Our results provide empirical evidence on two substantive aspects. In the first place, we ratify the empirical relevance of Translog harvest functions at the fisheries studied (see also Peña-Torres and Basch 2000, Peña-Torres et al. 2003). This aspect has implications of interest for fisheries that face cyclical fish abundance. The Translog technology implies that changes in the scale of input use, or in fish abundance, do not affect fishing yields proportionally. On the contrary, the degree and sign of the impact are conditioned by the scale of fishing. Thus, it is possible and likely that different abundance cycles could involve different values for the harvest-input elasticities; and associated with this, different marginal incentives to fishing.

However, in bioeconomic models for marine fisheries it is frequent practice to consider harvest functions of a linear type in fishing effort and the fish stock (*i*.e., the *Gordon-Schaefer* function; see Clark 1976, Bjorndal 1988), or else other variants of the Cobb-Douglas type (e.g., Bjorndal and Conrad, 1987; Bjorndal et al. 1993; Opsomer and Conrad 1994). In this case it is habitual to accept assumptions of constant and independent values from the scale of production for parameters such as the harvest-input elasticities, which have a direct incidence on fishing incentives.

On account of the foregoing, and above all for small pelagic fisheries, it is a modeling challenge of some interest to incorporate in a more explicit manner the phenomenon of "scale effects" suggested by the empirical validity of Translog harvest functions. One alternative would be to perform parametric sensitivity analysis, studying a range of values for the coefficients of key inputs, such as the fishing effort and biomass, in functions of the Cobb-Douglas type. This would contribute to the analysis of aspects such as the presence of multiple equilibria, marginal fishing incentives in each case, and the conditions of local stability in those equilibria of greater relevance. All these aspects are directly relevant for the study of cyclical fisheries. This line of analysis may help to better understand the adjustment processes that are more likely to occur when moving between one cycle of abundance to another.

In the second place, our estimates identify a set of effects acting as disincentives to adjust towards a lower scale of fishing effort. On one hand, the sensitivity of harvests in the face of changes in fish abundance decreases as fish stocks become scantier. On the other hand, our results show two sources of increasing average returns in fishing operations:[28] (a) increases in the scale of the own fishing effort; and where the strength of this effect increases, the greater the fishing capacity of the vessel is. The second source is due to (b) positive production externalities associated to the aggregate fishing effort (yearly haul) of the fleet in operation.

If in addition to the estimation results obtained, we also consider the elements of sunk cost and prolonged economic life that usually characterize the capital invested in industrial fishing fleets,[29] the spontaneous occurrence of cyclical fishing effort (i.e., pulse fishing strategies), as those modeled by Lewis and Schmalensee (1979, 1982), seems unlikely in contexts with fishing yields such as those analyzed in this paper.

In these cases, and to the extent that common-pool fish stocks continue producing excessive fishing, we confirm the relevance of considering precautionary type criteria when defining global catch quotas. However, if systems of tradable individual fishing rights were successfully attained, and also complemented with catch quota programs of a multi-annual nature (such as those nowadays used at pelagic fisheries in South Africa; Butterworth et al. 1997), it seems possible and likely that spontaneous pulse fishing strategies could acquire greater empirical relevance for fisheries subject to important cycles of fish abundance.

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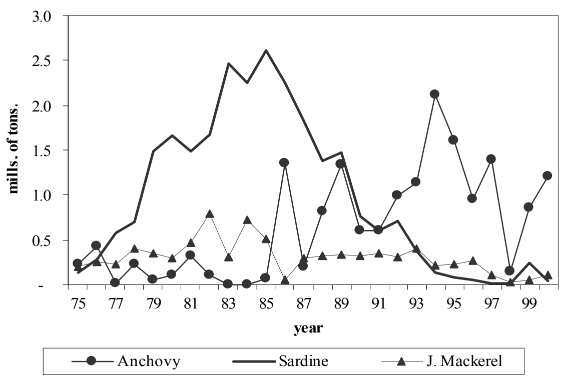
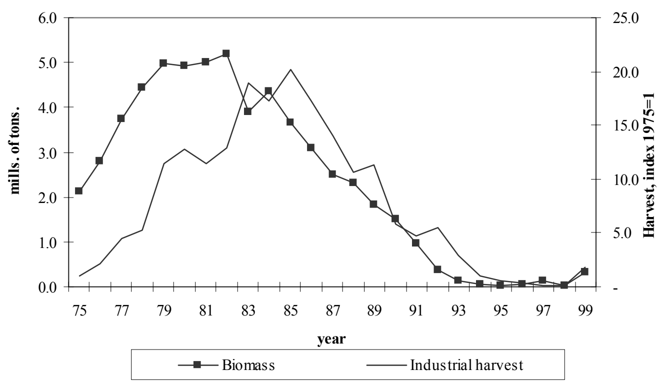
Annex 1: Northern Fishery (regions I and II)

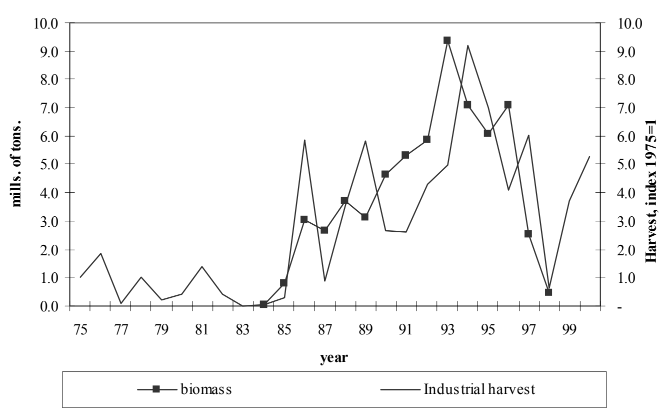
(1A) Three main fish species: Annual Landings (in millions de tons)



(1B) Pacific Sardine: Biomass and Industrial Fleet's Harvest
(in millions of tons and index, respectively)



(1C) Anchovy: Biomass and Industrial Fleet's Harvest[1]
(in millions of tons and index)



Source: Authors' elaboration, based on IFOP data.
[1/]: There exist records of anchovy biomass only for period 1984-98.

Annex 2: Stationarity Tests

Levin and Lin develop a unit root test using the following model specification (see Maddala and Kim, 1998):

$$\Delta X_{i,t} = \alpha_0 + \beta t + \gamma X_{i,t-1} + \Sigma_k \delta_k \Delta X_{i,t-k} + \varepsilon_{i,t} \quad \text{(a1)}$$

where: i = 1,...,N (N= total number of vessels) and t = 1,...,T (T= total number of periods). In this expression, ε_{it} ~ i.i.d. $(0,\sigma^2)$, as in the case of the traditional ADF tests of Dickey and Fuller. The relevant statistics for β and γ have the same non-standard asymptotic distributions when lags of the dependent variable are included, as in the case of the ADF tests. The null hypothesis being tested in (a1) is $H_0 : \gamma=0$ and $\beta=0$. In this equation, X_{it} corresponds to the natural logarithm of the variable of interest, which in our case corresponds to harvest, effort and effectiveness. Levin and Lin prove that asymptotically:

$$T\sqrt{N}\hat{\gamma} \sim N(0,2) \quad \text{(a2)}$$

$$t_\gamma \sim N(0,1) \quad \text{(a3)}$$

In the expression (a1), when the parameter $\gamma<0$, the process X is stationary in a stochastic sense. In turn, coefficient β measures the possibility of a deterministic stationarity when $\beta=0$.

Results: Modal Panels

	Northern Zone			**Central-Southern Zone**		
	Harvest	*Effort*	*Effectiveness*	*Harvest*	*Effort*	*Effectiveness*
β	-0.102	-0.037	0.005	-0.07	-0.02	-0.00
	(-8.05)	(-4.30)	(2.78)	(-6.12)	(-4.21)	(-0.02)
γ	-0.979	-1.00	-1.061	-0.820	-0.909	-0.810
	(-27.93)	(-28.79)	(-33.54)	(-14.90)	(-24.41)	(-19.11)
DW	2.04	1.91	1.90	2.09	2.11	2.16

Note: The traditional DW statistics for measuring autocorrelation in time series, when using panel based models, must be compared to critical values that differ from those found by Durbin and Watson (Bhargava, Franzini and Narendranathan, 1982). The t statistics are in parenthesis; to see their critical values, we need to resort to non-standard distributions.

Annex 3: Hausman Tests

The null hypothesis is that the random effects (RE) algorithm is consistent and more efficient than the fixed effects model. The alternative hypothesis implies that there exists a correlation between the regressors and the error term, in which case the random effects algorithm renders inconsistent estimations, whereas the fixed effects model continues to provide consistent estimators.

Ho: *RE model is valid*	**Northern fishery**		**Central-Southern fishery**		
	PN1	**PN2**	**PS1**	**PS2**	**PS3**
Chi^2	39.6	31.52	50.38	39.25	7.76
p value	0.001	0.035	0.000	0.001	0.850

Annex 4: Northern fishery (Parsimonious Models)

Explanatory Variables	**PN1** *(80-300 m^3)*				**PN2** (301-800 m^3)			
	FE		**RE**		**FE**		**RE**	
	Coeff.	*Test t*	*Coeff.*	*Test t*	*Coeff.*	*Test t*	*Coeff.*	*Test t*
Biomass (b)								
Haul (a)								
Hold (h_i)								
Effort (e_i)			0.82	6.66	1.10	42.61	19.31	2.89
Effectiveness (f_i)			64.30	2.24				
Age (g_i)							12.28	2.86
Trend (T)	83.64	10.76	31.49	11.79	55.55	4.25	23.60	10.37
b^2	17.47	6.73	0.05	6.88	10.69	2.58		
a^2	12.94	6.83	0.18	9.54	7.48	2.45	0.30	4.55
h_i^2							-0.39	-2..408
e_i^2	-0.03	-2.92	-0.02	-3.21				
f_i^2	1.10	2.82	0.59	2.29	0.96	-15.39	0.89	-12.54
g_i^2							-0.04	-3.13
T^2	-0.07	-7.47	0.00	-3.07	-0.04	-2.62		
$b \cdot a$	-29.21	-6.70			-18.13	-2.61		
$b \cdot h_i$					0.92	2.73	0.46	3.66
$b \cdot e_i$	0.09	10.09					-0.22	-2.36
$b \cdot f_i$	1.40	2.66			0.03	2.60	0.04	5.04
$b \cdot g_i$								
$b \cdot T$	-1.48	-8.11	-0.19	-6.23	-0.95	-3.05	-0.10	-4.94
$a \cdot h_i$					3.41	2.70		
$a \cdot e_i$							0.68	-2.30
$a \cdot f_i$	-0.98	-2.17	-3.28	-2.16				
$a \cdot g_i$							-0.57	-2.53
$a \cdot T$	-3.12	-12.02	-1.50	-12.38	-2.13	-5.03	-1.18	-10.91
$h_i \cdot e_i$			0.10	10.95			-0.27	-4.23
$h_i \cdot f_i$								
$h_i \cdot g_i$			-0.07	-3.54			-0.25	-3.14
$h_i \cdot T$					0.07	2.90	0.08	4.48
$e_i \cdot f_i$	-0.18	-2.14						
$e_i \cdot g_i$			0.03	2.32				
$e_i \cdot T$	-0.01	-2.26	-0.02	-6.83			-0.01	-2.27
$f_i \cdot g_i$								
$f_i \cdot T$	-0.08	-3.62	-0.10	-3.76				
$g_i \cdot T$								
D 87	0.93	6.83			0.67	2.96		
D 88	0.30	5.52			0.31	4.32	0.07	2.33
D 89			0.20	6.25	0.25	3.86	0.34	9.05
Adjusted R^2	0.96		0.96		0.97		0.97	
F	305.1				689.2			
Wald			10830				13143	
M (# observations)	1206		1206		693		693	
N (vessels)	151		151		99		99	

FE: fixed effects; RE: random effects

Annex 5: Central-Southern fishery (Parsimonious Models)

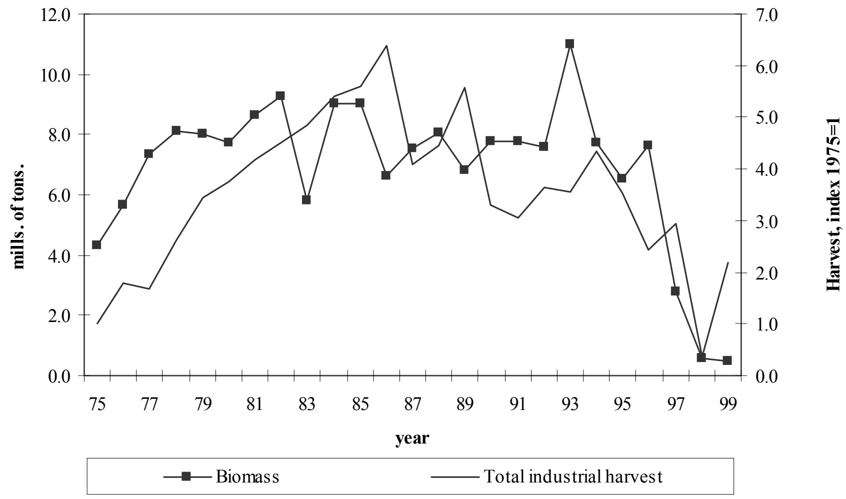
	PS1 *(80-300 m^3)*				**PS2** *(301-800 m^3)*				**PS3** *(301-800 m^3)*			
	FE		**RE**		**FE**		**RE**		**FE**		**RE**	
Variable	*Coeff.*	*Test t*	*Coeff.*	*Test t*	*Coeff*	*Test t*	*Coeff*	*Test t*	*Coeff.*	*Test t*	*Coeff.*	*Test t*
B												
A												
h_i			22.78	6.51			13.89	5.95	-104.01	-3.33		
e_i					1.64	7.37			-10.18	-2.52		
f_i											-5.77	-2.82
g_i												
T	76.84	5.72	-9.32	-5.80	15.17	2.97	-5.94	-4.85				
b^2	28.87	6.44	0.05	2.54	6.73	3.83	0.04	3.43	-1.14	-3.68	-1.57	-3.95
a^2	26.20	6.42			6.03	3.78					1.54	4.02
h_i^2	1.71	3.35							1.16	2.16		
e_i^2					-0.03	-2.23	-0.03	-3.29	-0.12	-6.22	-0.10	-5.69
f_i^2									8.20	2.86		
g_i^2					-0.26	-5.48	-0.05	-5.32			-0.07	-3..63
T^2	1.95	6.27	-0.08	-5.46	0.40	3.33	-0.08	-4.87			0.11	3.44
$b \cdot a$	-54.08	-6.43			-12.6	-3.81						
$b \cdot h_i$									4.83	3.04	7.39	3.88
$b \cdot e_i$									0.81	3.23	0.18	12.13
$b \cdot f_i$	-2.04	-3.63					-0.80	-2.22				
$b \cdot g_i$	-0.88	-2.58							0.82	3.43		
$b \cdot T$	11.87	6.53			2.62	3.70	-0.15	-4.85	-0.37	-4.49		
$a \cdot h_i$	-0.97	-3.41	-1.23	-6.27			-0.76	-5.86			-7.32	-3.94
$a \cdot e_i$	0.16	3.65	0.11	6.14			0.09	11.36				
$a \cdot f_i$	2.00	3.79			0.07	13.92	0.83	2.51				
$a \cdot g_i$	1.22	2.88	0.13	2.84	0.02	3.68			-0.82	-3.46		
$a \cdot T$	-15.74	-6.32	0.52	5.95	-3.35	-3.49	0.44	5.09			-0.93	-4.31
$h_i \cdot e_i$												
$h_i \cdot f_i$												
$h_i \cdot g_i$												
$h_i \cdot T$	0.16	2.69	0.17	4.26	0.04	3.50	0.17	6.54	0.85	4.36	2.33	4.37
$e_i \cdot f_i$									0.67	4.23	0.87	3.37
$e_i \cdot g_i$	-0.57	-2.28	-0.33	-2.96								
$e_i \cdot T$												
$f_i \cdot g_i$			0.44	15.83					-0.77	-2.85		
$f_i \cdot T$	-0.44	-3.99					-0.18	-2.97				
$g_i \cdot T$							0.02	3.60	0.26	3.26	0.03	3.28
D 87	0.28	2.75	-0.48	-2.50			-0.35	-2.74				
D 88			-0.33	-3.07			-0.16	-2.37	-0.74	-3.95		
D 89	0.39	4.58			0.141	3.70			-0.54	-5.69		
Adjusted R^2	0.94		0.93		0.95		0.92		0.95		0.96	
F	113.9				167.8				241.2			
Wald			4826				8907				3546	
M	459		459		741		741		143		143	
N (Vessels)	64		64		102		102		43		43	

M: Total number of observations

Figure 1: Chilean Pelagic Fisheries

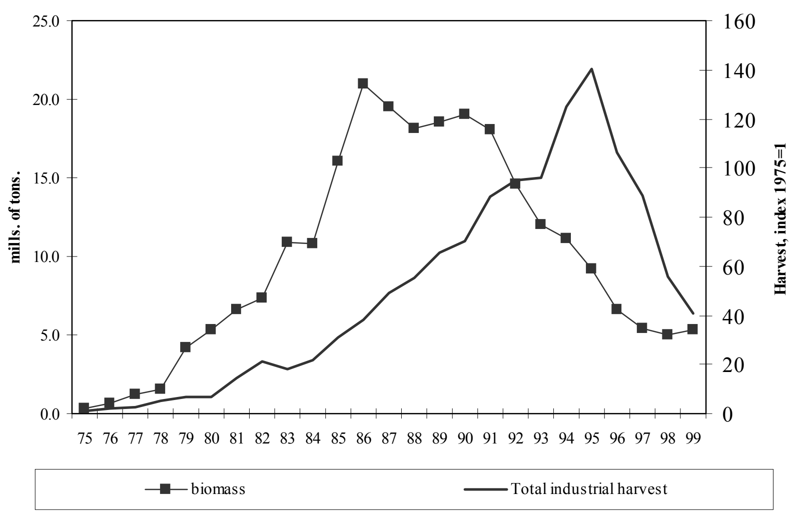
(A): Northern Fishery
(B): Central-Southern Fishery

Graph 1:
Northern Fishery
Biomass and Industrial Fleet Harvest (3 main species[1])
(Biomass in millions of tons, and Harvest in index)



1/: There exist records of anchovy biomass only for period 1984-98.

Graph 2:
Central-Southern fishery
Jack Mackerel Biomass and its Industrial Harvest
(Biomass in millions of tons, and Harvest in index)



Source (both Graphs): Authors' elaboration based on IFOP data.

Table 1

Year	**Northern fishery** (Industrial Fleet)					**Central-Southern fishery (**Industrial Fleet)				
	(1) Annual Haul (index)	*(2) Number of vessels*	*(3) Hold capacity (m^3,10^3)*	*(4) Total Biomass (tons 10^6)*	*(5) Annual Harvest (tons, 10^6)*	*(6) Annual Haul (index)*	*(7) Number of Vessels*	*(8) Hold capacity (m^3,10^3)*	*(9) Total Biomass (tons, 10^6)*	*(10) Annual Harvest (tons, 10^6)*
1985	100.0	192	48.3	11.1	3.09	100.0	97	27.8	17.2	0.952
1986	104.8	192	48.6	8.8	3.31	142.4	93	29.5	22.0	1.127
1987	106.5	193	49.7	9.3	2.23	157.0	93	32.7	21.0	1.528
1988	108.3	197	51.7	10.1	2.34	192.7	105	40.0	20.3	1.704
1989	110.7	195	52.7	8.75	2.87	231.6	108	48.4	21.8	2.001
1990	103.8	180	49.0	9.9	1.61	302.3	140	60.3	21.95	2.091
1991	104.6	183	53.2	9.5	1.54	356.0	174	76.3	20.9	2.868
1992	96.9	164	49.9	8.5	1.89	412.7	173	78.7	15.8	2.881
1993	101.1	159	48.6	11.7	1.76	440.8	172	90.8	14.3	2.617
1994	95.8	145	45.6	8.1	2.20	511.8	167	97.2	13.0	3.423
1995	100.0	134	40.4	7.1	1.72	640.3	177	110.4	12.0	4.024
2001*					1.00					1.505

Source: *IFOP* and Yearly Fishing Statistical Annals (*Sernapesca*).

(1),(6). Haul: $A_t = \sum_i H_{it} * E_{it}$ ($\forall$i that operates in year t), where H_{it} = hold capacity and E_{it} = yearly fishing hours (for vessel i en year t).

(2),(7). Number of industrial vessels operating at the fishery.
(3),(8). Hold capacity of all industrial vessels operating in year t.
(4),(9). Aggregate exploitable biomass (recruitment and older cohorts) for 3 main species, plus a remainder which was extrapolated for other minor species.
(5),(10). Yearly total harvest (total species) for all industrial vessels operating in year t.
*/: year 2001: Industrial harvest (4 main species. In the Northern zone, mackerel is added to the 3 main species. In the Central-Southern, Chilean hake is added to the 3 main species).

Table 2
Number de vessels operating in each fishery
(Estimation sample data)

	Northern		**Central-Southern**		
Year	*PN1*	*PN2*	*PS1*	*PS2*	*PS3*
1985	131	61	48	29	.
1986	132	60	47	41	.
1987	131	62	40	47	.
1988	132	65	31	58	.
1989	128	67	31	64	6
1990	118	62	42	72	10
1991	112	71	43	79	13
1992	93	71	33	77	17
1993	87	72	30	85	25
1994	76	69	26	79	39
1995	75	59	20	84	39
Total[1/]	**151**	**99**	**64**	**102**	**43**

Source: Authors' elaboration based on IFOP data.
[1/] This total adds up all the vessels which recorded fishing operations in at least 1 year during the period 1985-95.

Table 3: Harvest-Input Elasticities
(*using sampling period averages, 1985-95*)

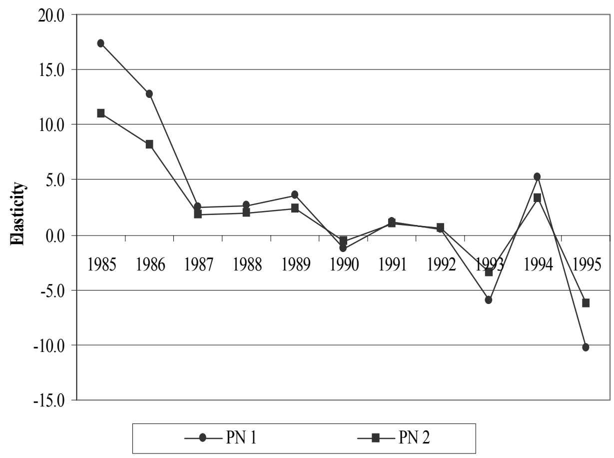
	P1 (FE)		**P2 (FE)**		**PS3**	
Zone→	Northern	Central-Southern	Northern	Central-Southern	**FE**	**RE**
Biomass (b_{t-1})	2.55	2.53	1.82	0.73	0.89	0.16
Haul (a_t)	-0.32	0.3	-1.94	-0.37	-1.86	1.82
Effort (e_{it})	0.98	1.14	1.1	1.18	1.24	1.17
Age (g_{it})	*ns*	4.4	*ns*	-0.96	-0.25	-0.13

FE: Fixed Effects; RE: Random Effects
ns: non significant.

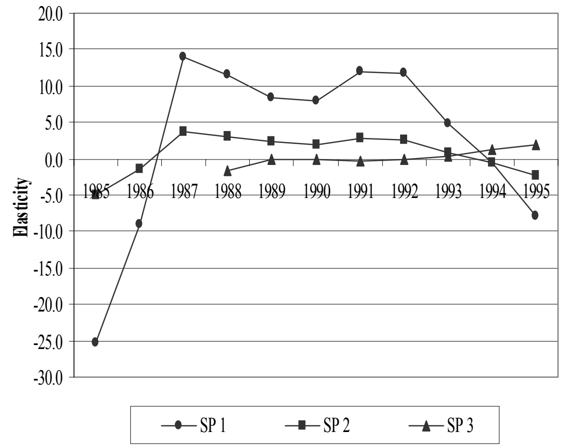
Graph 3: Harvest-Biomass Elasticities

(1) Point estimates based on yearly averages for each variable:

(A) Northern Fishery

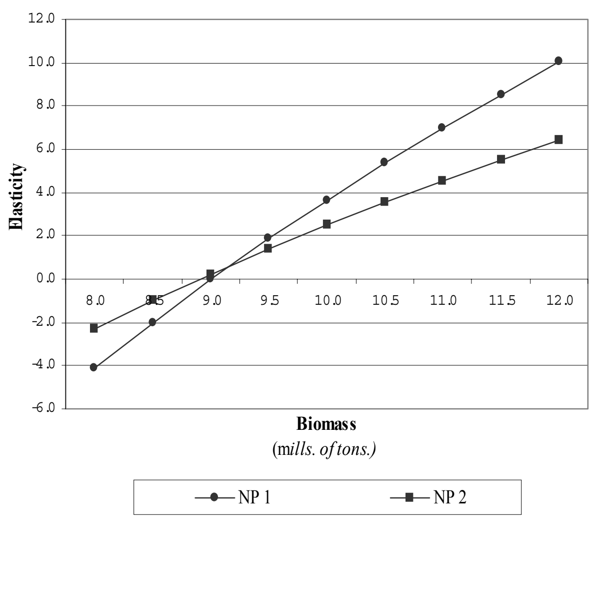


(B) Central-Southern

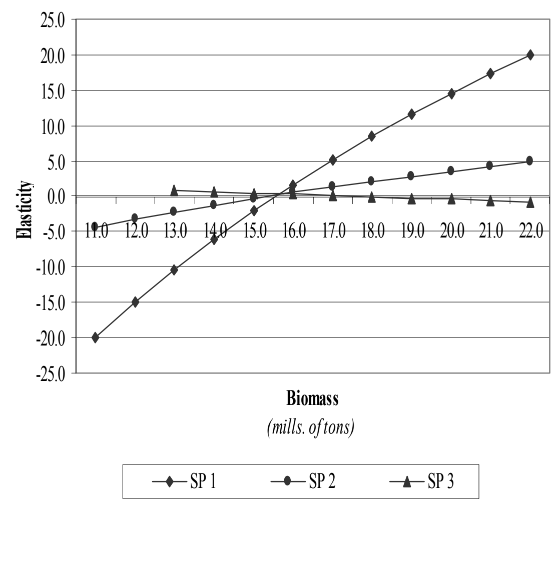


(2) Point estimates based on ceteris paribus calculation:

(A) Northern Fishery



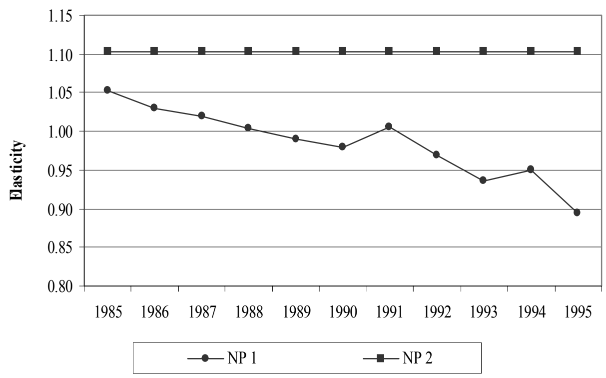
(B) Central-Southern



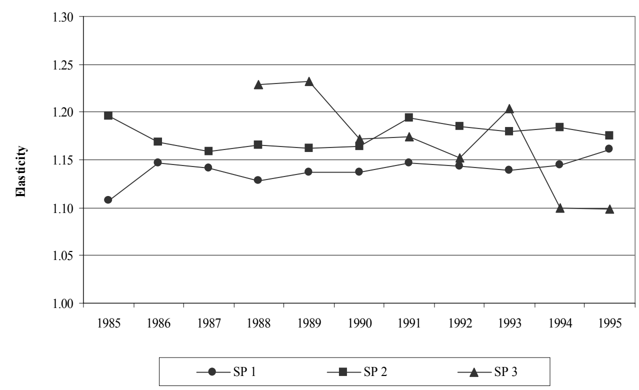
Graph 4: Harvest-Effort Elasticities

(1) Point estimates based on yearly averages for each variable:

(A) Northern Fishery

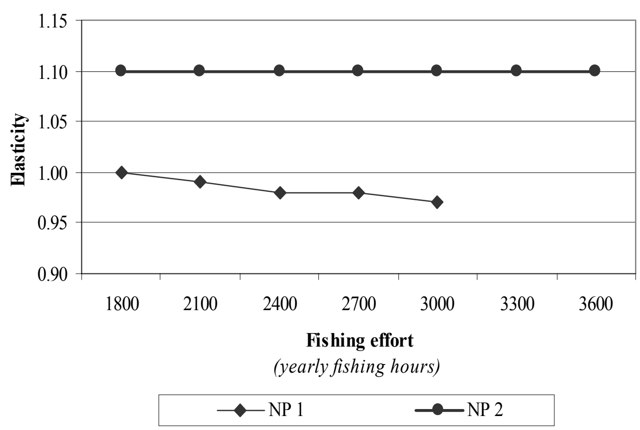


(B) Central-Southern

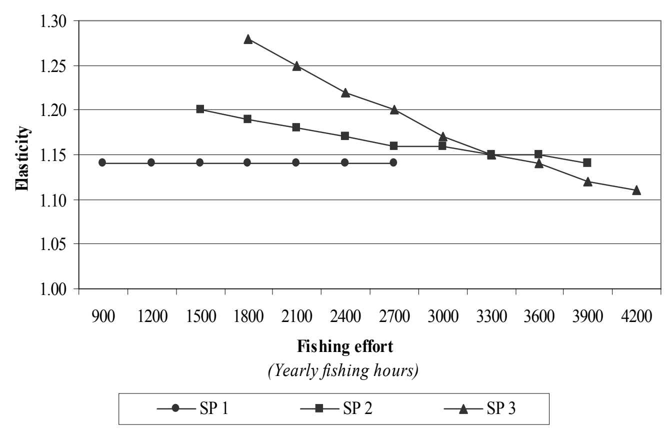


(2) Point estimates based on ceteris paribus calculation:

(A) Northern Fishery



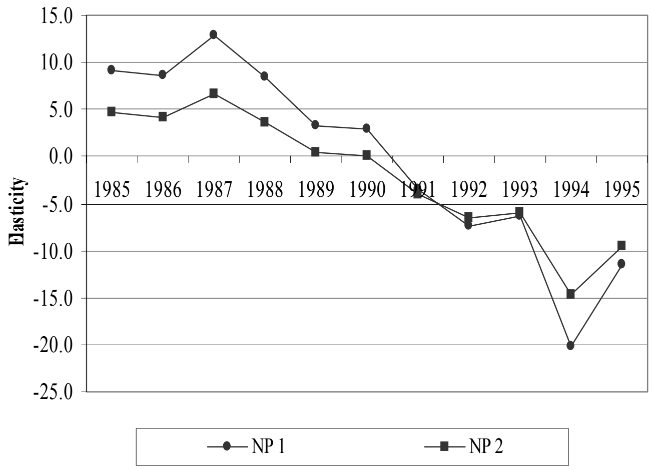
(B) Central-Southern



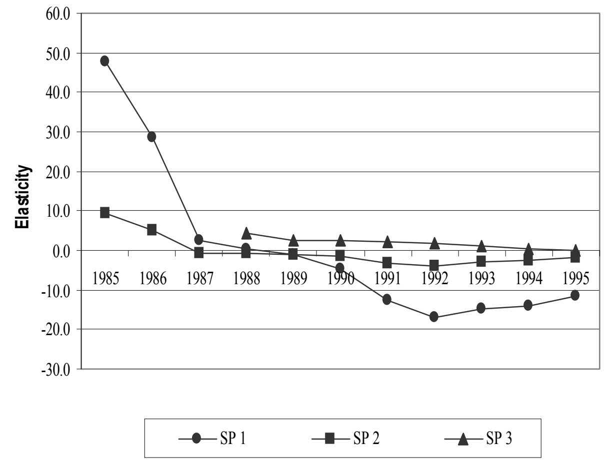
Graph 5: Harvest-Haul Elasticities

(1) Point estimates based on yearly averages for each variable:

(A) Northern Fishery

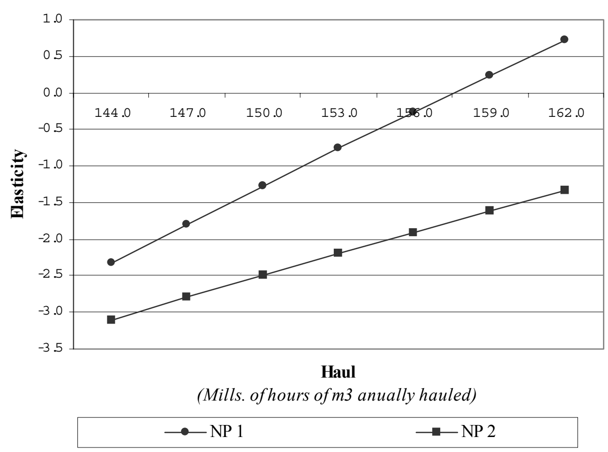


(B) Central-Southern

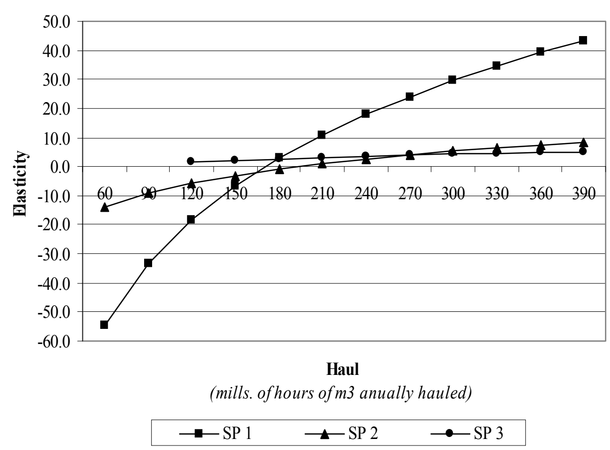


(2) Point estimates based on ceteris paribus calculation:

(A) Northern Fishery

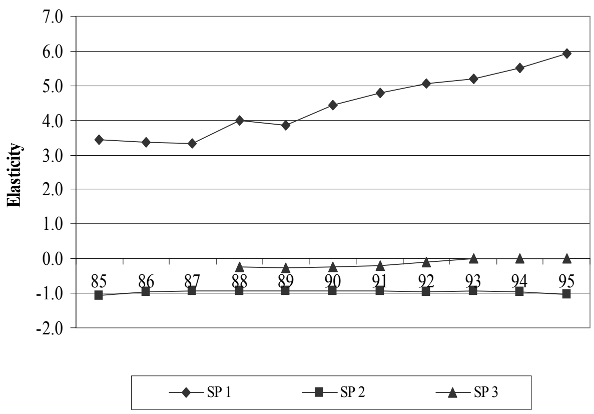


(B) Central-Southern

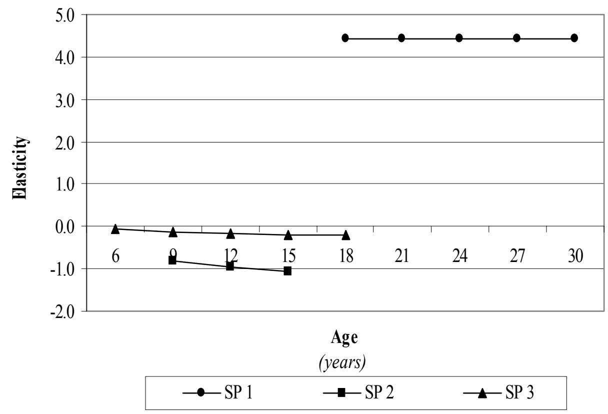


Graph 6: Harvest-Age Elasticities
(Central-Southern fishery)

(1) Yearly averages for each variable



(2) *Ceteris paribus est*imates



[1] We gratefully acknowledge financial support from *Fondecyt Project # 1000764*, as well as access to data and information offered by *IFOP* and the Fisheries Undersecretariat personnel. We are particularly grateful for comments and clarifications received from P. Barría, R. Serra, C. Bernal, R. Pinochet and M. Perticara (UAH). Remaining errors in this paper are the authors' sole responsibility.

[2] This is due to the fact that small pelagic fish dwell at a low depth (not more than 50-100 m), and additionally move about and migrate in large and dense schools.

[3] Despite this, Bjorndal (1988) develops a bioeconomic model for this fishery under the assumption of constant returns to fishing effort.

[4] For this same fishery, the estimation exercises in Bjorndal (1988, 1989) assume that there exists a total independence between harvest and fish abundance. However, Bjorndal (1989) points out that his estimation results do not support the assumption of null value for the harvest-abundance elasticity.

[5] Let q be the catchability coefficient, with $q_t=(C_t/E_t)/X_t$ and where C_t is the harvest in period t, E the fishing effort, and X the fish stock. Csirke (1988, p. 289) mentions studies on different pelagic fisheries, where the estimated values for q vary inversely with X. Using a relationship such as $q= aX^b$, a series of studies have estimated values for b in the range [-0.3, -0.9]. If the harvest function were of a Cobb-Douglas type, and where the fish stock is a state (input equivalent) variable, obtaining an estimated value b<0 would imply a lower value (all the rest being constant) for the harvest-abundance elasticity.

[6] In the year 2000, industrial landings represented 78% of the total volume of fish landed in Chile (industrial and artisanal fishing, that is, 3.5 million tons.). Total fish landings in Chile involve a yearly exported value that is close to US$1000 millions.

[7] Given standing access regulations during the sampling period, the fleets in each fishery operated in a completely independent manner. Something similar occurs with the main fish stocks exploited in each zone; though jack mackerel could be an exception to this case. Currently, there exists a debate as to the possibility that the jack mackerel stocks in either zone could be part of a common growth and migratory biological process.

[8] In recent years, the share of jack mackerel has risen over 95%.

[9] Relationships of biological competition between sardine and anchovy stocks, involving alternated cycles of abundance, is a phenomenon also documented for other pelagic fisheries in the world (see Csirke and Gumy 1996, McEvoy 1986, Cushing 1988, Sahrhage and Lundberk 1992, and Luch et al. 1992).

[10] During these years the possibility of assigning individual fishing quotas, on the basis of historical catch records, was debated. These discussions began towards the end of 1987 and still proceeded in the midst of an intense controversy until the final enactment of a new Fishing Law in 1991.

[11] The first vessels over 800 m^3 of hold capacity started operating in this fishery in 1989. In 1995, vessels in and above this size category represented 44% of the total hold capacity displaced by the industrial fleet operating in the Central-Southern fishery.

[12] It is *El Niño* of greatest intensity observed during the XXth century. However, it is a commonly held opinion by insiders to the Chilean fishing sector that overinvestment and overfishing also contributed to the declining dynamics in catch levels.

[13] During the sampling period, there are vessels whose hold capacity varies; in general, it expands. Besides, in this period there are vessels that enter and others that leave the fleet, whereby the variable corresponding to hold capacity of the vessels presents fluctuations in time.

[14] In the case of jack mackerel, recruitment is at two years of age, for anchovy at six months and for Pacific sardine at three years.

[15] This method estimates the age distribution of a fish population on the basis of historical information on harvest age composition. Through backward extrapolation of fish abundance (number of fish by cohort), together with assumptions on natural mortality and harvest rates, the population age distribution is estimated. This distribution is subsequently adjusted by cohort average weights, from which the biomass estimations are finally derived (Serra and Barría, 1992).

[16] The panels defined consider characterizations that *IFOP* makes regarding technological differences in the fishing capacity of different sized vessels.

[17] Zellner at al. assume that the firm maximizes its expected earnings and that in this process the businessman makes non systematic errors. If these errors are not correlated with environmental shocks, Zellner et al. prove that a OLS estimation procedure will provide *consistent* estimators for the parameters of the production function. Their proof assumes that the variables approximating input use are choice variables. Thus variables

controlled by the crew of each vessel (e.g. fishing effort) can be considered as if they were (observationally) exogenous; and on a similar logic, the hold capacity and age of the vessel.

[18] For pelagic species the key aspect is to have a robust model on the biological determinants of the recruit population.

[19] The test in question is a variant of Hausman's usual test (Hausman, 1978), through which it is tested whether a subset of variables, originating from a larger set made up of all the variables whose exogenous character could be a matter of doubt, are actually exogenous (Maddala, 1992). In our case, the variables of interest were all the variables whose exogeneity could be dubious (this excludes vessel's hold and age), except biomass and the terms that contain it. The results were, according to an F test of the Wald type, for the Northern fishery: F=1.32 (p=0.25); and for the Central-Southern fishery: F=2.25 (p=0.06). These values are consistent with the Zellner et al.'s hypothesis of exogeneity. The instruments used were the same variables lagged by one year. When making a similar test, in this case considering as variables of interest only fishing effort and biomass (together with all its squared and crossed terms), we obtain for the modal panels PN1: F=4.56 (p=0.00); and for PS2: F=3.99 (p=0.00). The instrument used for biomass is the total fleet's harvest lagged by one year. This result supports apprehensions regarding the exogenous character of the biomass. We expect to address this problem in a future paper in a more robust manner.

[20] The decision of whether or not to set a biological closure is conditioned by a set of different factors (among others, political negotiations); therefore it is not obvious at all that this decision should have a significant correlation with catch yields at the vessel level.

[21] This test was not applied to the variables biomass and haul, given their limited extension as time series.

[22] Information on initial estimates of the general model can be provided by the authors on request.

[23] It is a well documented phenomenon that pelagic fish stocks tend to increase the density of their schools as their abundance falls, as a defensive mechanism against natural predators (Csirke, 1988)

[24] If we test the null hypothesis (H_0) that the harvest-effort elasticity has unitary value, using the average 1985-95 values reported in Table 3, Wald tests clearly reject H_0 in each one of the panels of the Central-Southern zone (at 95% of confidence); the same occurs with PN2. Only in the PN1 case it is not possible to reject H_0, in a reasonable range of % of confidence (p-value of 0.149).

[25] The panel PN2 is the exception, showing only negative values for the harvest-haul elasticity (ceteris paribus values). The plotted ranges of yearly haul levels only consider values observed during the sampling period.

[26] Bjorndal et al. (1993) state a similar conjecture when attempting to explain their estimated result of increasing fishing returns in the face of increases in the number of vessels in the fleet. The authors suggest that this could be due to information sharing between vessels, regarding the location of seals in exploitation.

[27] Two considerations could contribute to explain the statistical non-significance of this variable in the North: (a) during the sampling period, the Northern fishery experienced nothing similar to the intense process of entry of new ships that was observed in the Central-Southern zone. (b) Fishing in the north is mainly coastal and thus relatively easier to attain than in Central-Southern zone (here the spatial domain of the fishing effort is broader). Both considerations could imply that effects of technological obsolescence or from cumulative

learning (effects which the variable age seeks to control for) do not have in the North a similar explanatory power as in the Central-Southern fishery, with respect to inter-vessel differences in fishing yields.

[28] This differentiation between two sources of increasing fishing returns is not clear in prior empirical studies (e.g. Bjorndal and Conrad 1987; Bjorndal 1989; Bjorndal et al. 1993).

[29] At the end of 1995, the age of the vessels analyzed at both fisheries ranged between 20-25 years. On the other hand, both fleets studied face very few alternative uses, given that in Chile since the mid of the 1980s there prevails closed access at all most relevant industrial fisheries. And this being part of a regulatory context whereby fishing permits are specific to the vessel, to a given fishing area as well as to one species in particular; without there existing (as yet) any trading option to transfer the fishing permit from one closed-entry fishery to another (see Peña-Torres, 2002).