

ECONOMIES OF SCALE AND STOCK-DEPENDENCE IN  
PELAGIC HARVESTING: THE CASE OF NORTHERN CHILE\*

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ABSTRACT

*Pelagic species are one of the fish stocks which are most vulnerable to unrestrained fishing. Their initial abundance has been a source for substantial profits in the past, with several fishing collapses resulting from it. This paper analyses the case of the pelagic industrial fishery of Northern Chile, estimating harvesting functions which contribute to understand why weak exit incentives may predominate in pelagic fisheries, despite scarcer fish stocks. For the modal vessel size we obtain a catch-to-stock elasticity positive but lower than one. This is consistent with an inverse relationship between a Schaefer-type catchability coefficient and fish biomass. However, as predicted by marine*

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*biologists, our results suggest that the degree of catch's stock dependence is stock-level specific. Also for the modal vessel size, we obtain increasing returns in the use of per-vessel fishing effort and a positive (search) externality resulting from aggregate fishing effort. For smaller vessels, the latter implies a stronger positive external effect. Moreover, we obtain robust indications of prevailing economies of scale in harvesting operations all across our estimation sample, which helps understand the observed technological substitution favoring larger vessels. We end by discussing pending research challenges which may help improve management decisions in Northern Chile and other pelagic fisheries.*

## 1. INTRODUCTION

Marine industrial fisheries (MIFs) fit closely into the standard paradigm of the tragedy of the commons, where 'too numerous and too small' participants tend to exploit *too much* of a common-pool resource. For pelagic fish<sup>1</sup> the analogy becomes even *more tragic*, as shown by the history of pelagic collapses (Cushing, 1988; Gulland, 1988). A crucial and pending question is why increasingly scarcer fish stocks, do not trigger more frequently similar-speed reductions in the number of smaller-scale fishing units, presumably those with higher average costs.

This paper performs econometric estimations of harvesting productivity parameters which help to understand why *weak* exit incentives may sometimes prevail in fishing industries, particularly in those catching pelagic fish. Besides, it focuses on exploring how fishermen's choices of vessel size, taken as a first-order approximation for choices regarding firm's scale of operation<sup>2</sup>, are conditioned by productivity issues related to the nature of the fishing grounds under exploitation. We study the case of the pelagic fishery of Northern Chile between the mid-1980s and early 1990s, period with a declining productivity trend which triggered some degree of exit among the smaller-firms in this fishery, though the total fishing capacity of the operating fleet remained without great variations.

In addition to conditions which favour easy entry to profitable marine fisheries (e.g. low human and financial capital requirements; free access substantiated on equity considerations), overfishing has been facilitated by a striking time-endurance of small-scale operations at marine fisheries, particularly

<sup>1</sup> In general, pelagic fisheries are more abundant but more variable than other fish stocks, e.g. demersal species. Pelagic fish tend to be short-lived and faster growing versus demersal ones, hence more vulnerable to recruitment fluctuations. They also tend to have significant migratory patterns. They are fish with darker and more oily flesh (vs. demersal ones), hence they tend to be less attractive for direct human consumption. Historically, processing of pelagic fish has been dominated by reduction industries.

<sup>2</sup> Information on scales of operation at the firm level (firms' fleet ownership and their operation) is usually much more difficult to access than information codified at the vessel level.

at fishing grounds off coasts where low-factor-mobility communities have developed. Numerous small vessels, in most cases administered separately by small-scale and family-tied-owned firms, tend to be a long-lasting outcome of initially massive entry processes to fisheries in early stages of industrial development.

Unsurprisingly, the time-endurance of numerous small-scale decision-making units tends to be positively correlated with the persistence of common-property conditions. As an example, we can think of traditional small-scale agriculture and communal grazing activities, frequently facing overexploitation inefficiencies while operating under ill-defined private property rights, usually involving low-quality land plots (e.g. Dasgupta, 1993; Scott, 1990). Big numbers, particularly those involving cost-heterogeneous participants, increase the costs of organising collective action aimed at rationalising common-pool uses and therefore reduce the chances, *ceteris paribus*, for their eventual evolution into private property rights.

There are numerous factors which could be relevant when attempting to explain the time endurance of small-scale operations at MIFs<sup>3</sup>; perhaps different ones when attempting to explain causal links between scales of operation and the evolution of common property rights. However, none of these two concerns are primary targets in this paper. Instead, scale considerations are narrowed down to focus on fishermen's choices of vessel size, and how they are conditioned by harvesting productivity. We estimate and analyse fishing effort's marginal productivity, catch's stock-sensitivity, and resulting (dis)-economies of scale in harvesting operations.

We explore these issues by estimating Cobb-Douglas and Translog harvesting functions, at the vessel level, resorting to panel data on the industrial fleet operating at the pelagic fishery of Northern Chile. There are no previous studies on these lines for Chilean MIFs. The estimation sample consists of annual information (1985-93) on industrial harvesting and fishing effort, for a fleet of 99 purse seiners. Our estimations also make use of official annual stock assessments for the three most important pelagic stocks under exploitation. This is a multi-species fishery, with sardine, anchovy and jack mackerel catches accounting for nearly 90% of total catches. Currently, it is the second most important MIF in Chile, with an average annual total catch (1985-93) of nearly 2.5 million tons.

We estimate harvesting functions which do not differentiate between species caught. This is due to three main reasons: (i) the *generalist* (multi-species)

<sup>3</sup> Just to mention a few examples: (i) Governments' frequent support (i.e. subsidies) to small-scale operations, based on equity/political considerations; (ii) efficiency and risk-sharing advantages of personalized, long-lasting and interlinked trading, between fish-processors/-traders and small-scale harvesters; (iii) financial penalties related to highly uncertain catches and sunk capital's risk exposure; (iv) capital-rationing on small-scale operators, due to fishermen's difficult-to-assess (monitor) idiosyncratic characteristics (e.g. Doeringer and Terkla, 1995, ch.3; Platteau, 1989; Platteau and Nugent, 1992).

industrial fleet under study, (ii) the predominance of a reduction industry (fish meal production) as a key demand sector, implying no significant price differentials between different species catches, and (iii) our intention to estimate catch's stock-sensitivity to changes in the *aggregate* availability of the main fish stocks, as biological interdependencies between the main species imply non-trivial risks of misspecification in species-specific estimation exercises. Our modelling of harvesting functions includes a proxy for the aggregate availability of the main fish stocks. It also considers proxies for per-vessel and aggregate fishing effort. The latter aims to account for the possibility of contemporaneous technological externality effects (congestion or search externalities). This paper proceeds as follows. Section 2 describes key features of the fishery under study. Section 3 discusses the harvesting model analysed. Section 4 describes the estimation data. Section 5 discusses our estimation methodologies and the results obtained. Section 6 offers a concluding discussion.

## 2. THE PELAGIC FISHERY OF NORTHERN CHILE

This is a multi-species fishery, with three main species (sardine, anchovy and jack mackerel) accounting for around 90% of total catches. Peruvian waters are the northern boundary of these fishing grounds, implying some degree of transboundary migration<sup>4</sup>. The area under study covers nearly 750 kms of longitude, with most harvesting taking place (by a Chilean-owned fleet) within Chilean waters<sup>5</sup>.

As other small-shoaling pelagic multi-species fisheries around the world (Csirke, 1988), this one has shown historically a high degree of catchability, with the three main pelagic species sharing the characteristic of moving together in densely populated groups, at relatively low depths<sup>6</sup>. Since the start of its industrial development in the mid-1950s, this fishery's abundant catches have been mainly used for reduction (fish-meal and oil production). Total catches showed a steady increase all along the 1970s and the mid-1980s, with the maximum annual catch reached in 1986. Since then, persistent fishing pressure

<sup>4</sup> According with *Chilean Development Fisheries Institute* (IFOP)'s calculations, around 60% of the anchovy stock found in Chilean waters shows migratory patterns to Peruvian waters. The transboundary proportion of the sardine stock seems to be much smaller (less than 10%). There is no clear evidence of transboundary migration for the jack mackerel stock.

<sup>5</sup> The jack mackerel stock has migratory patterns towards open sea. However, a significant part of these migrations to international waters occur in areas further South than the fishing grounds considered in this study. Since the mid-1970s and until the late 1980s, the ocean-going Soviet fleet had a significant share of the jack mackerel catches in international waters of the Southeast Pacific. In the late 1980s, the Soviets caught annually around 1 million tons of jack mackerel in international waters close to the Chilean EEZ (Crone-Bilger, 1990).

<sup>6</sup> The anchovy, for instance, has a vertical distribution which in general does not exceed 50 meters of depth (Yañez, Barbieri and Barra, 1986).

has contributed to trigger a declining trend<sup>7</sup> in the aggregate availability of the three main fish stocks (proxied by the sum of their biomasses). In turn, this has triggered declining annual catches (Tables 1 and 2).

TABLE 1  
INDUSTRIAL FLEET (ESTIMATION SAMPLE)

Years	Annual harvest (all species) per vessel (tons, 10 <sup>3</sup> )	Annual fishing trips per vessel (number of trips)	Annual harvest/SC per vessel (times*)
average 1985-86	21.3	159	82
average 1992-93	10.6	138	41

Source: Own calculations based on IFOP's statistics. It considers 99 industrial purse seiners with 130ESCE380 m<sup>3</sup> (our estimation sample, accounts in 1985-93 for 62% of the total annual catches); \*: here SC (storage capacity) has been transformed from m<sup>3</sup> to tons.

TABLE 2  
AGGREGATE DATA

Years	Aggregate effort (index)	Industrial fleet		Harvest (tons; 10 <sup>6</sup> )		Biomass (tons; 10 <sup>6</sup> )	Harvest/Biomass (%)
		Number of vessels	SC (m <sup>3</sup> ; 10 <sup>3</sup> )	Total	3 main species	3 main species	3 main species
1985	100.0	177	43.4	3.155	3.057	14.312	21.4
1986	119.7	186	46.6	3.604	3.354	8.269	40.6
1987	121.3	193	49.5	2.345	2.212	11.185	19.8
1988	108.9	187	47.3	2.490	2.347	9.473	24.8
1989	121.9	193	51.2	3.039	2.875	7.949	36.2
1990	102.5	185	50.8	1.772	1.490	8.335	17.9
1991	99.7	182	52.2	1.733	1.377	9.235	14.9
1992	108.7	159	47.9	2.066	1.811	6.546	27.7
1993	110.8	157	46.6	1.915	1.672	7.078	23.6

Source: Own calculations based on IFOP's data.

Total Harvest: all fish species caught by industrial fleet's catches.

Biomass: Sum of *economically exploitable* biomasses of jack mackerel, sardine and anchovy (IFOP's annual stock assessments).

Aggregate fishing effort =  $\sum_i (t_i)(SC_i)$ , where  $t_i$  are the annual fishing trips of vessel  $i$  and  $SC_i$  is  $i$ 's storage capacity.

Sardines have been the worst affected stock. Official (IFOP's) stock assessments indicate that the exploitable biomass of sardines in 1992-93 was only 10% of the maximum level that this stock achieved in the early 1980s. Correspondingly, sardine catches have declined from representing 83% of the

<sup>7</sup> The strongest "El Niño" this century, which peaked in the winter of 1982-83, is estimated to have contributed to this result.

regional industrial catches in 1985, to 18% in 1993. As in other multi-species pelagic fisheries around the world, the decline of the sardine stock has occurred in parallel to a recovery, though with significant annual fluctuations, in the anchovy stock<sup>8</sup>. In 1992-93, anchovies represented a bit more than 50% of the regional industrial catches, while in the early 1980s anchovy catches were negligible. Jack mackerel catches in this region showed an increasing trend since the mid-1970s until the mid-1980s, when a decline — though less pronounced than in sardine catches— started. The jack mackerel stock in the early 1990s has been estimated to be at nearly a third of its maximum regional level which was reached in 1985 (IFOP's stock assessments).

As a response to signs of declining stocks and a risk of overfishing, the regulatory agency imposed a freezing policy on the fleet's storage capacity starting in 1986. Since then entry regulations have been combined with seasonal closures. Partly as the result of enforcing (though imperfectly; Peña, 1996c) these regulations, and partly as an endogenous response to declining harvesting productivity, aggregate fishing effort in the early 1990s has decreased from the peak levels achieved in the late 1980s (Table 2).

The number of purse seiners operating in the area reached a maximum in 1987. Since then it has gradually declined. However, the fleet's storage capacity has remained without great variations since the mid-1980s. This reflects an increasing substitution in favour of larger vessels: while the most frequent storage capacity (SC) range corresponds to 230-380 m<sup>3</sup> per vessel, the participation of larger vessels —some of them with a SC of up to 1,000 m<sup>3</sup>— increased from 4.5% of the total number of vessels in 1985 to 20% in 1993. By contrast, the number of vessels in the smaller size categories (e.g. with SC£ 180 m<sup>3</sup>) has declined from 60 in 1985 to 37 in 1993<sup>9</sup>.

Since 1991 to date, the three main pelagic fish species have been declared to be in a state of *full exploitation*, which empowers fishery authorities to establish, in addition to entry restrictions, global and individual catch quotas. However, these have been unsuccessful (Peña, 1997)<sup>10</sup>.

The combined effect of multi-species interdependencies, the highly variable nature of the fish stocks, and the lack of long time-series statistics for these fishing grounds, make the empirical testing of the hypotheses behind these failures a very difficult task. This is reflected in the current lack of sufficiently robust scientific knowledge on the behaviour of these fish stocks<sup>11</sup>. This imposes

<sup>8</sup> Csinke and Gumy (1996, p.36) offer evidence for the Peruvian post-1973 anchovy/sardine fishery; McEvoy (1986, p.216) describes a similar phenomenon for the drop of the Californian sardine stock through the 1950s; Cushing (1988, p. 253) and Sahrhage and Lundberk (1992, p.260) offer additional evidence for sardine/anchovy relationships off the South African coast in the early 1960s and off the Namibian coast in the late 60s.

<sup>9</sup> Nearly 2/3 of these smaller boats are owned by firms classifiable as "small" — according with the owned fleet's tonnage. (IFOP unpublished statistics).

<sup>10</sup> Quota proposals have always been species-specific, without an explicit consideration of possible species interdependencies among the main fish species under exploitation.

<sup>11</sup> This tends to be a shared weakness with the scientific knowledge which is available for other pelagic fishing grounds around the world.

a restriction upon the quality of bioeconomic analysis that is currently feasible for these fisheries. Acknowledging the importance of improving the understanding of the biological issues involved, this paper leaves aside a thorough discussion of these issues. Our focus is on studying the productivity incentives which are present in the actual harvesting technology.

An important feature of the industrial fleet operating in Northern Chile is the absence of species-specialised vessel technology. It is well-known that the latter imposes additional constraints upon the regulations for a common pool fishery (e.g. Clark, 1985, ch.5). The generalist (multi-species) purpose of this fishing fleet seems to be heavily influenced by the uncertain and highly variable nature of the main pelagic stocks under exploitation. In a highly fluctuating environment, a multi-species fleet can act as a form of insurance against uncertain cycles in individual species' availability<sup>12</sup>. Indeed, Csirke (1988), commenting on multi-species pelagic systems, argues that "fluctuations of an individual stock are usually much wider than that of the three or four main shoaling pelagic fish stocks taken together".

A second reason for the generalist character of this fishing fleet is related to demand prices. Pelagic species in this region are mainly demanded by a reduction (fish-meal and fish-oil) industry. This implies no significant differentials between prices for the catch of each of the main stocks.

Given the economically similar character of the main pelagic stocks under exploitation, the generalist character of the fishing effort carried out by the fleet under analysis, and the current lack of adequate knowledge (growth patterns and species interdependencies) of the fishery under exploitation, we treat different fish species as equal ones in our estimations. Indeed, we use catch data which aggregate all species harvested, and proxies for fish stocks' aggregate availability which add up total tonnage resulting from official (IFOP's) biomass assessments for individual species.

The purpose of this simplified approach is, while reducing risks of significant misspecification problems<sup>13</sup> in the estimation exercises, to take into consideration the varying availability of the main fish stocks under exploitation. Although this approach precludes the testing of hypotheses concerning multi-species interdependencies (e.g. anchovy-sardine relationship), it allows us to

<sup>12</sup> Theoretical analyses supporting a causal link between uncertain and fluctuating fish stocks and the existence of generalized (multi-species) harvesting technologies can be found in McKelvey (1983) and Lipton and Strand (1989).

<sup>13</sup> An explicit differentiation among catches and biomass assessments of the main fish species may imply important misspecification risks in our econometric estimations. At least two of the three most important species are expected to have 'some degree' of systematic interdependency. However, neither the particular nature of these biological interdependencies, nor the time-series cycles involved in them are well understood so far. Scientific knowledge on these issues is still subject to important controversy, in particular regarding recruitment functions which show significant random behaviour. Though it is clearly advisable to pursue research in this direction, such an effort is beyond the scope of this study.

proxy and test in a simple and parsimonious way a possible stock-dependence of the vessels' catch (across species) per unit of effort. A lower (higher) stock-dependence of catches per unit of effort tends to increase (reduce), *ceteris paribus*, the risk of collapse of a given commercial fishery. A weak stock dependence is another way of referring to a weak marginal stock effect, using the standard nomenclature in the capital-stock approach to the theory of renewable resources (e.g. Clark, 1976). As is well known, a weaker (stronger) marginal stock effect tends to imply, *ceteris paribus*, a stronger (weaker) positive correlation between discount rates and optimal stock depletion levels.

Testing the feature of catch's stock-dependence, even as a first-order approximation, is particularly relevant for the case of pelagic fisheries. It is frequently assumed that the schooling behaviour of pelagic species implies unit harvesting costs which tend to be stock-independent (except for *very low* stock levels; e.g. Clark, 1982), increasing the vulnerability of pelagic stocks to fishing effort. This is certainly an important argument when explaining the fishing collapses which have occurred elsewhere (see Cushing, 1988; Gulland, 1988). In the extreme case of no stock-dependence, the literature speaks of 'pure' schooling behaviour (e.g. Bjorndal, 1989). In a more general case, pelagic fisheries have often been described as implying catches with *weak* stock-dependence (e.g. Clark, 1982; Csirke, 1988). The latter has been interpreted as implying a catch-to-biomass elasticity which is positive but lower than one (e.g. Hannesson, 1983)<sup>14</sup>. In the case of Chilean pelagic stocks, the authors are not aware of explicit testing on this issue.

### 3. HARVESTING MODEL

Our estimations consider a per-vessel harvesting function of the following general type:

$$(1) \quad H_{it} = f(E_{it}, B_t, A_t, \theta_{it})$$

where  $H_{it}$  denotes total tonnage harvested (considering all fish species) by vessel  $i$  in year  $t$ ,  $E_{it}$  a proxy variable for vessel  $i$ 's use of variable inputs (a variable that we call 'fishing effort'),  $B_t$  is a proxy variable for fish stocks' aggregate availability,  $A_t$  is a proxy for the aggregate fishing effort of the entire fleet operating during year  $t$ ; and  $\theta_{it}$  summarizes random (natural and man-originated) events affecting the harvesting success of vessel  $i$  in year  $t$ .

<sup>14</sup> This can be deduced by combining the biological hypotheses described in Csirke (1988) and Bjorndal (1988). This interpretation is based on supposing that the catchability coefficient (' $q$ ' in the linear Schaefer harvesting function) is inversely related to the stock level (e.g.,  $q=dX^{-a}$ , with  $X$  denoting stock level, and  $d$ , a constant parameters).



The strategy of collapsing all variable input choices into a single variable has well-established roots in fishery economics, resting on the assumption that input ratios tend to be *relatively* fixed in fishing operations.  $E_{it}$  is expected to be positively associated with  $H_{it}$ . However, per vessel harvesting is also conditioned by fixed investment in the vessel's fishing capacity. This is a multi-attribute variable. Searching technology (e.g. sonar, airplane's support), engine power, fishing gears, storage capacity, and captain's idiosyncratic fishing knowledge are some of the fixed factors which help explain differences in vessels' catch success. However, it is beyond our sample's information to attempt to cover these attributes.

In our estimations we proxy the vessels' fixed fishing capacity by grouping individual vessels into representative size categories, according to their storage capacity. As a general norm, one would expect a significant positive correlation between the fishing potential related to the different fixed attributes in each vessel. Hence, differences in vessel size should behave as relatively good predictors of differences in other fixed fishing-power attributes. Our estimations will provide information for representative categories of vessels, each one characterising an average range of fishing power attributes.

The expected sign for the effect of variable  $A_t$  on harvesting is unknown a priori. Its possible relevance within the harvesting function can be related to two different effects: on the one hand, the increasing scarcity of the main stocks could have occasioned *congestion* externalities (i.e. contemporaneous rival consumption) between competing vessels. On the other hand, the *schooling* behaviour of pelagic stocks is expected to generate some degree of external economies when searching for migratory, high density, fish patches. Indeed, there is some evidence that searching effort from the more sophisticated vessels tends to generate positive effects on smaller vessels' harvesting (Peña, 1996a)<sup>15</sup>.

Based on a priori principles, one would expect  $H_{it}$  to show some degree of positive correlation with  $B_t$ . But the significance of this correlation, its evolution as harvesting scales change, and possible changes as the vessel size varies, are all unknown. Regarding this correlation, it would be interesting to test the marine biologists' frequent assertion that, for these species, stock's density tends to decrease less than proportionally to reductions in its biomass (e.g. Csirke, 1988). This is usually interpreted as a harbinger of collapse risks as biomass falls. The empirical validity of this assertion can be tested on estimations of the *catchability coefficient* ( $q$ )<sup>16</sup>. If mean harvests (per unit of fishing effort) are positively associated to the stock's density, then the relationship between stock's biomass

<sup>15</sup> Though individual vessels have different searching abilities, once an important shoal is detected by one (some) vessel(s) of the fleet, information of its location quickly spreads out among other active vessels operating nearby.

<sup>16</sup> It is usually defined as the ratio between mean harvest (per unit of fishing effort) and the exploitable biomass of a given fish stock. In the notation of equation (1), it corresponds to  $(H_{it}/E_{it})/B_t$ . This is the traditional "q" coefficient in the Schaefer linear harvesting function (where  $q$  is assumed to be constant).

and stock's density would imply an inverse relationship between the catchability coefficient and biomass levels: if biomass were to drop, we should expect 'q' to increase. In a Cobb-Douglas harvesting function, for instance, this is equivalent to obtaining the estimated biomass-coefficient positive but lower than one (e.g. Hannesson, 1983).

Our estimations will basically compare Cobb-Douglas (CD) and Translog functional forms for equation (1). Both functions have been previously used for estimating harvesting functions in other fisheries<sup>17</sup> (e.g. Hannesson, 1983; Bjorndal and Conrad, 1987; Bjorndal, 1989; Kirkley, Squires and Strand, 1995)<sup>18</sup>. The CD form is a convenient first-order approximation for testing differences in the value of input elasticities across different vessel categories.

Nonetheless, CD functional forms imply well-known technological restrictions (Heathfield and Wibe, 1987; Chung, 1994). The scale-insensitivity imposed by a CD function on the values of input elasticities and the elasticity of scale, for a given vessel category, are of special relevance for this study<sup>19</sup>. The scale-sensitivity of input and scale elasticities will be tested by estimating a Translog harvesting function (which also allows input and scale elasticities to vary with the scale of harvesting).

As shown by equation (1), we consider one-equation models, with  $H_{it}$  as the single endogenous variable. This approach is discussed after describing our data.

#### 4. DATA

All the data was obtained from the Chilean Fisheries Development Institute (IFOP). It includes annual information (1985-93) on harvesting and fishing effort at the vessel level, for the Chilean industrial fleet operating off the coasts of Northern Chile (between Arica and Antofagasta), and time series consisting of IFOP's estimated annual biomasses for the three main pelagic species in this fishery.

<sup>17</sup> A series of other recent empirical studies on fisheries have focused their estimation exercises on Translog cost or revenue functions (e.g., Morey, 1996; Salvanes and Steen, 1994; Campbell and Nicholl, 1994). However, none of these studies refer to pelagic stocks; their focus involves different research objectives (e.g. Salvanes and Steen aim at testing to what degree the stochastic environment affects the relative catch performance of vessels between fishing seasons in the Norwegian sealing fishery of Newfoundland; Campbell and Nicholl aim at testing to what degree purse seiners can target specific species in the Western Pacific tuna fishery).

<sup>18</sup> Both Hannesson and Kirkley *et al.* consider the estimation of stochastic production frontiers. This method has been normally used for analyzing technical (in)efficiency (inputs' optimal mix) issues. None of these two studies refer to pelagic species.

<sup>19</sup> The restriction (i.e. the unitary value) imposed on the substitution elasticity is less relevant in our context, as this paper is not aimed at studying the scope for input-substitutions in harvesting operations.

Catch data considers the total tonnage caught (all fish species) by each individual vessel, for each year within the sample. Given our focus on catch's stock sensitivity to changes in the *aggregate* availability of the main fish stocks, we proxy fish stocks' changing abundance by an annual variable which sums up the estimated total (across age cohorts) annual biomass (in tons) of the three main pelagic species. The biomass levels considered correspond to the economically exploitable stocks<sup>20</sup>. This includes recruitment and older age cohorts. Recruitment occurs at two years of age for the jack mackerel, at three years for sardines, and at six months for anchovies.

IFOP's stock assessments are based on Virtual Population Analysis (VPA; see Gulland 1988). This method estimates a given fish stock's age distribution starting from historical information on catches' age composition. By combining the latter, expressed in number of individuals per age cohort, with age-specific estimations for natural and fishing mortality rates, the stock's age composition (expressed in number of individuals) is reconstructed backwards in time. The resulting stock's age distributions (for different years) are then adjusted by an estimated average weight matrix<sup>21</sup> (according to age cohort and year in the sample), from where biomass estimations are finally obtained (e.g. Serra and Barría, 1992).

The fleet's aggregate fishing effort in year  $t$ , denoted by  $A_t$ , is proxied by  $A_t = \sum_i (Z_{it})(SC_i)$ , where  $Z_{it}$  denotes the number of fishing trips<sup>22</sup> of vessel  $i$  in year  $t$ , and  $SC_i$  is  $i$ 's storage capacity, measured in  $m^3$  (constant across the years studied). The sum covers the entire fleet for each year. Ideally, one would also like to consider differences in trips' duration across vessels of different sizes. Unfortunately, information on trips' duration was unavailable to the authors. Hence, individual fishing effort is proxied by the annual number of fishing trips which vessel  $i$  made during year  $t$  ( $Z_{it}$ ). Possible resulting estimation biases are discussed later. However, these shouldn't be too strong since the entire fleet operates near the coastline.

For estimation purposes we selected, from the total sample of industrial purse seiners, only those vessels which were active *all* along the 1985-93 period (99 vessels in total). This group corresponds, on annual averages, to 62% of the fleet's total harvest and 55% of its total tonnage capacity for the sample period. The excluded vessels were the larger ones in the fleet (i.e. those with  $SC_i > 380 m^3$ ), as they started to enter this fishery on a gradual basis since 1985.

20 IFOP's biomass estimations for the jack mackerel and anchovy stocks considered an area larger than the fishing grounds studied in this paper. Hence, when constructing our proxy variable for the aggregate availability of fish stocks, the jack mackerel's and anchovy's biomass estimations were weighted by the ratio between catches in the Arica-Antofagasta area and catches in the entire sea area considered by IFOP's estimations.

21 Age-cohort-specific average longitudes are first calculated from the historical catch's age composition, and then age-cohort-specific average weights are obtained by applying a catch-sample calculated (weight/longitude) relationship.

22 This considers  $i$ 's fishing trips with and without success in obtaining catches.

The vessels selected were divided into three size-categories, depending on their storage capacity: group 1 (130-179 m<sup>3</sup>) includes 22 vessels; group 2 (180-229 m<sup>3</sup>) includes 8 vessels; and group 3 (230-380 m<sup>3</sup>) includes 69 vessels (this is the *modal* size for the fleet). This choice of size ranges is taken from IFOP's (1988) official characterisation of the industrial fleet under study.

All variables were first transformed to indexes (1985=100), and then to natural logarithms so that the estimated coefficients could be interpreted directly as input elasticities. In terms of mathematical notation, from now on we will use lower case letters for denoting the natural log of the corresponding variable (e.g.,  $x = \ln X$ ).

## 5. ECONOMETRIC ESTIMATION

### *Endogeneity*

In *strictu sensu*, all three explanatory variables in equation (1) could eventually be modelled as endogenous variables, requiring the estimation of a simultaneous system of equations. However, given the *per-vessel* nature of our harvesting model, an assumed exogeneity for the *aggregate* variables  $B_t$  and  $A_t$  is probably less contentious than a similar assumption for per-vessel fishing effort.

In order to verify whether or not per-vessel and aggregate fishing effort can be considered as if they were exogenous variables, given the format of our estimation sample, Hausman exogeneity tests were carried out with the instrumental variable  $z_{it}$  for per vessel effort and the corresponding variable for aggregate effort  $a_t$ . To implement these tests, the variables  $z_{it-1}$ ,  $b_{t-1}$ ,  $a_{t-1}$  and  $h_{it-1}$  were used as instrumental variables for  $z_{it}$  and  $a_t$ . The null hypotheses that per vessel trip and aggregate effort are exogenous variables could not be rejected (at 99% significance), neither for small nor large vessels in the estimation sample. The F tests were 1.14 and 1.21, respectively. This fact has crucial consequences when estimating models like that exemplified by (1). Indeed, although fishing effort could be an endogenous variable, depending on the time unit and aggregation scales considered in the estimation exercise, in our sample it has proved to be independent from the error term. Hence, for our estimation purposes, per vessel and aggregate fishing efforts can be considered as if they were both exogenous. This leaves variable  $B_t$  as the only possible endogenous variable that could be correlated to the error term. To overcome this problem, we use biomass lagged one period as an instrumental variable for  $B_t$ .

Given the caveats above, there is no need for treating our estimation problem as if it were a simultaneous equations system. This result can be further strengthened if we resort to the classical argument first put forth by Zellner,

Kmenta and Drèze (1966)<sup>23</sup>. Assuming that input decisions are based on profit-maximization behavior, Zellner, Kmenta and Drèze argue that if output is stochastic due to uncontrollable shocks such as weather, firms will select inputs to maximize *expected* profits assuming risk-neutrality. However, in stochastic environments, the argument runs, entrepreneurs will most probably make nonsystematic errors (the authors speak of managerial inertia or random human errors) in their attempt to adjust inputs to satisfy the necessary conditions for profit maximization. When these random human errors are not correlated with the stochastic shocks from Nature in the production function, Zellner, Kmenta and Drèze prove that the estimation of a production function by classical least squares yields *consistent* estimators.

### *Stationarity*

It is necessary to verify whether the variables in our estimation exercise are stationary in time in order to avoid possible spurious regression problems. Should the variables be non-stationary, the usual t and F statistics do not follow the traditional Student and Fisher distributions, respectively. In this case it would be virtually impossible to make any sense regarding the statistical significance of the estimated parameters. To check for this issue, we perform unit-root tests similar to those of Dickey and Fuller (1979, 1981) but now correcting for the presence of cross-sections in line with the results of Pesaran and Smith (1995) and Abuaf and Jorion (1990). The results are shown in Appendix 1. According to these results, the four variables in our estimation sample are stochastically stationary with high significance values; notwithstanding, all of them show a marked deterministic tendency.

Regarding the deterministic trend effect, the tendency present in each variable should be eliminated by either regressing the variable against time and rescuing the residuals or by including the time variable explicitly in the regressions to be considered. Our analysis uses the former option<sup>24</sup>. Hence, all following estimations consider detrended variables.

### *Harvesting functions*

Let us begin writing expression (1) as a Cobb-Douglas multiplicative model:

$$(2) \quad H_{i,t} = \alpha_{0i} Z_{i,t}^{\alpha_1} B_t^{\alpha_2} A_t^{\alpha_3} e^{\mu_{i,t}}$$

<sup>23</sup> For example, Kirkley *et al.* (1995) recur to this argument for justifying treating per-vessel fishing effort as an exogenous variable in their estimation of a per-vessel catch (per trip) function.

<sup>24</sup> The results obtained when estimating the harvesting functions using both alternatives are very similar.

The variables were already defined, except that we now use  $m_{i,t}$  which is the stochastic error term associated with per vessel harvesting. We use  $Z_{i,t}$  as an instrumental variable to measure vessel  $i$ 's fishing effort at time  $t$ , and  $A_t$  for proxying the possibility of a contemporaneous technological externality.

We have defined model (2) in a panel format. The latter implies some convenient features when estimating a production function such as (2). First, by using only time-series, multicollinearity problems can appear throughout, making the interpretation and measurement of individual parameters cumbersome. This pitfall is diminished by using panel samples. Second, given that we will not study expression (2) as part of a simultaneous equations system, possible identification problems and resulting simultaneity biases are avoided to a large extent. It is known that by adding cross-sectional data these problems can be considerably lessened (Koutsoyiannis, 1986; Greene, 1993; Baltagi, 1995). In our case, this seems to be confirmed by the results obtained from the Hausman exogeneity test. We additionally reduce the risk of simultaneity biases by introducing an adequate instrumental variable for the fish stock variable.

We consider three separate subpanels (the first with 22 vessels, the second with 8, and the third with 69 vessels), all of which are estimated simultaneously. This way of grouping individual vessels is based on IFOP's (1988) official classification regarding vessels' technological homogeneity. We also experimented with alternative classifications. For example, we grouped the subpanels with 22 and 8 vessels. As we report later, no significant changes were obtained versus the initial classification with three subpanels. Hence, to keep consistency with IFOP's classification, the results that we discuss are based on the latter case. For the sake of brevity and robustness in the exposition, the coefficients estimated for the intermediate subpanel (8 vessels) are not discussed<sup>25</sup>. The estimations obtained for this group imply no qualitative change versus the relative patterns of the estimations for the other two more representative subpanels. Hence, in what follows we discuss the estimations for the subpanel including 22 vessels with storage capacities between 130-179m<sup>3</sup> (denoted as  $S1$ ), and the results for the subpanel including 69 vessels with storage capacities between 230-380 m<sup>3</sup> (denoted as  $S2$ ).

Notwithstanding the merits of a panel data estimation, precision problems in the estimated parameters can arise. This can be due to idiosyncratic differences among the vessels in our sample. In addition to individual trips, it would be desirable to consider other differentiating variables (e.g. engine power, searching technology). Unfortunately, this information was unavailable to the authors. Nonetheless, the methodology used lessens this problem by resorting to a "fixed effects" model. This consists in making explicit the dependence of coefficient  $a_0$  on vessel  $i$ . The other coefficients ( $a_1$ ,  $a_2$  and  $a_3$ ) are assumed to be constant for all vessels, within a given subpanel, throughout the period under study.

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Information on these results can be obtained on request from the authors. The small number of vessels in the intermediate subpanel weakens the robustness of the estimated coefficients for this group.

*A log-linear Cobb-Douglas function: scale-invariant input and scale elasticities*

The first econometric model which we estimate is a log-linear Cobb-Douglas harvesting function, using the one-period lagged aggregate biomass as an instrumental variable for fish stocks' aggregate availability,

$$(3) \quad h_{it} = k_i + \alpha_1 z_{it} + \alpha_2 b_{t-1} + \alpha_3 a_t + \mu_{it}$$

Estimating (3) by means of a *fixed effects* panel model we obtain consistent estimators for all parameters (if  $\mu_{it}$  is normal, then the estimators are also asymptotically efficient). Furthermore, we used White's (1980) methodology to assure a heteroscedasticity-consistent covariance matrix of the estimated parameters. There was no need to use the stricter Newey-West procedure (Newey and West, 1987), since no autocorrelation was found<sup>26</sup>. We estimated the referred subpanels simultaneously, resorting to dummy variable techniques in order to enhance the efficiency of the estimated parameters. The results are shown in Table 3.

TABLE 3  
COBB-DOUGLAS HARVESTING FUNCTION

Explanatory Variable	S1	S2
Minimum Intercept	-32.18 (-8.15)	-14.77 (-7.58)
Maximum Intercept	-31.20 (-7.90)	-14.14 (-7.25)
$z_i$	0.86 (12.81)	1.20 (24.66)
$b(-1)$	0.95 (8.65)	0.53 (10.78)
$a$	1.35 (5.97)	0.63 (5.52)
D.W	1.89	
F	59.73	
$R^2$	0.90	
n	792	
log L	273.38	
B.I.C.	-2.62	

Note: t-statistics in parentheses, n is the number of observations, log L is the logarithm of the likelihood function, D.W. the Durbin-Watson statistic, F is Fisher's statistic and B.I.C. is Schwarz's bayesian information criterion. S1: vessels (N=22) with Storage Capacity (SC) between 130 and 179 m<sup>3</sup>; S2: vessels (N=69) with SC between 230 and 380 m<sup>3</sup>.

<sup>26</sup> This result applies to all the estimated harvesting functions. The rejection of the null corresponding to the presence of autocorrelation is based on results similar to the traditional DW tests but now considering the presence of cross-sections using the tables provided by Bhargava, Franzini and Narendranathan (1982).

Comparing subpanels S1 and S2, we see that the estimated coefficients differ in relation to each other. Therefore, it is not valid to group them into a single panel comprising all 91 vessels<sup>27</sup>. Furthermore, the *fixed effects* estimation technique is validated since the null that all intercepts are equal, within a given subpanel, is significantly rejected for both subpanels<sup>28</sup>. Even though, at first sight, in both subpanels the intercepts apparently do not vary much, they cannot be assumed to be equal. This confirms our prior of differentiating characteristics among individual vessels.

All the estimated elasticities are strongly significant. The estimated effort elasticities show a declining marginal productivity for fishing effort at the small vessel level (group S1), while showing increasing marginal productivity for vessels in group S2<sup>29</sup>. This result suggests that the larger vessels probably try to harvest as much as they can. The difference in marginal returns from fishing effort favors investment in larger vessels, as long as profits can be gained from the fishery. This is precisely what has been consistently observed in Northern Chile over the last decade. The increasing introduction of ever larger vessels (some with storage capacities over 1,000 m<sup>3</sup>) into these fishing grounds leads us to conjecture that increasing returns from fishing effort could well prevail, perhaps even be stronger, for even larger vessels vis à vis those in S2.

The observed difference between effort elasticities in groups S1 and S2, includes the effect from trips' different duration in one group versus the other. If we were measuring fishing effort by days at sea instead of number of trips, we would probably observe a smaller difference between the estimated effort elasticities. Unfortunately, information on trips' duration, at the vessel level, was not available to us. Nonetheless, we did obtain information on trips' annual average duration, for each category of vessel size, during 1990-94 (IFOP). Fishing trips of vessels in S1 had an average duration of 20 hours, whereas trips of vessels in S2 lasted on average 25 hours. In each group, annual deviations from these averages were very small.

Let us suppose that trips' duration is constant, across vessels and years, within each group S1 and S2, during the sample period. A first order approximation adjustment, accounting for the different average duration of vessels' trips in S1 versus S2, implies an effort elasticity for group S2 which is

<sup>27</sup> To see whether our results are robust to variations in the way the estimation sample was classified, we included the 8 medium sized vessels (with storage capacity between 180-229m<sup>3</sup>) in subpanel 1 and repeated the estimation exercise. The estimated parameters changed only slightly for this new category: 0.87; 0.86 and 1.35 for effort, lagged biomass and aggregate effort respectively. These results justify our sample selection procedure.

<sup>28</sup> At 95% and 99% levels the null is rejected with F tests equal to 8.83 and 4.46 for subpanels 1 and 2, respectively.

<sup>29</sup> The t test for the null that the individual effort elasticity is greater (smaller) than or equal to one, for groups S1 and S2 respectively, is equal to -2.09 (4.11), hence they can be rejected at a 97.5 (99.5) %-confidence level.



still 12% higher than the corresponding one for S1<sup>30</sup>. This suggests that the productivity differentials giving incentives to replace small boats by larger ones is still a valid argument had fishing effort been measured differently.

The fact that the estimated biomass elasticities are significant and positive suggests that vessels in the sample are vulnerable to variations in the aggregate availability of fish stocks. This result does not support the hypothesis of pure schooling behavior, i.e. that variations in fish stock levels do not have significant effects upon catch per unit of effort. Bjorndal (1989) used this argument to justify an *ex ante* exclusion of biomass proxies from his estimation of per vessel harvesting functions for the North Sea herring fishery (also a pelagic species). His results, however, led Bjorndal to reject the hypothesis that the stock elasticity was zero in that fishery. Our results for Northern Chile also provide evidence against this hypothesis. However, as will be argued later, one needs to condition the latter remark in terms of the fish stock levels prevailing along the time period under discussion.

The hypothesis that the value of the biomass elasticity is greater than or equal to one cannot be rejected for group S1 (t test of -0.46), but is definitely rejected for subpanel S2 (t test of -9.55) at any conventional level of significance. The latter result supports the frequent presumption that, for pelagic stocks, the fish stock's density tends to decrease less than proportionally vis à vis reductions in its biomass. Other things being equal, the latter feature increases the risk of a fishing collapse.

One may conjecture that the different biomass elasticities obtained for S1 and S2 reflect different capacities to adjust fishing effort to changes in the spatial distribution of the more productive fish patches. Larger vessels might be less vulnerable to fish stock variations, due to their greater maneuvering capacity and search capabilities. The different biomass elasticities also suggests that smaller vessels' productivity is more quickly affected as fish stocks become scarcer. This would be consistent with the observed gradual exit of smaller vessels in Northern Chile since the mid 1980s, when this fishery started its declining trend towards biological overexploitation. Nonetheless, caution should prevail when attempting interpretations covering a wide range of fish stock variations, as the estimated elasticities are assumed to be scale-insensitive in a Cobb-Douglas function. We come back to this issue when analyzing the estimation of a Translog harvesting function.

The positive sign obtained for aggregate effort, significant for both subpanels, could be a sign of external economies in the search for highly mobile fish patches. Smaller vessels would benefit from these external economies to a

<sup>30</sup> The estimated effort elasticities measure the percentage response of per-vessel harvest to percentage variations in the level of vessel's fishing effort. If fishing trips in vessel-size category  $i$  ( $Z_i$ ) had a *constant* duration of  $d_i$ , the percentage changes in fishing effort would then be  $Z_i d_i \%$ . In a simplified approximation, the trip's duration-adjusted ratio between the effort elasticities of groups S1 ( $i=1$ ) and S2 ( $i=2$ ) would then be  $(e_2/e_1)/(d_2/d_1)$ , with  $e_i$  denoting the estimated effort elasticity with fishing effort measured by  $Z_i$ .

greater extent than larger vessels, hence enjoying stronger free riding from aggregate searching effort. This is consistent with signs of a quick propagation of private (individual vessel's) information regarding the location of productive fish patches in this fishery (Peña, 1996a, ch.3).

Finally, allowing for variations in scale of use for *all* explanatory variables, including those not under the direct control of the vessels' crew, the estimation of the Cobb-Douglas functional form implies clear economies of scale (elasticity of scale greater than 1) for both subpanels, with the smaller vessels showing a larger elasticity of scale. Performing a test at a 95% confidence level, however, we cannot reject that economies of scale are equal for both subpanels. The sources for economies of scale in groups S1 and S2 differ: in the former, external (i.e. non-controllable) economies of scale are more important, whereas in the case of larger vessels (S2) internal economies seem to play a more important role. The presence of economies of scale in both subpanels, if true, implies an incentive for expanding harvesting scales (even more for vessel owners who are price-takers in input and output markets), which in turn should promote investment in larger vessels.

#### *Testing for the possibility of an U-shaped average harvesting cost function*

The scale-invariant elasticity of scale in a Cobb-Douglas production function implies that average harvesting costs maintain a monotonic relationship with the scale of production (in contrast with standard U-shaped average cost curves). The signs of economies of scale in vessels' harvesting is an invitation to explore the hypothesis of economies of scale using more flexible functional forms. Are we facing a case of pervasive economies of scale at all feasible levels of output, given the capacity constraints embodied in the vessels' size of our estimation sample? A first approximation to this issue is to estimate a generalization of the Cobb-Douglas production function proposed by Zellner and Revankar (1969). This generalization allows the elasticity of scale to vary with output<sup>31</sup> so that to reconcile a finding of (initial) economies of scale with an U-shaped average cost function (Greene, 1993: 324). In our case, the harvesting function to be estimated is

$$(4) \quad h_{it} + \theta H_{it} = k_i + \alpha_1 z_{it} + \alpha_2 b_{t-1} + \alpha_3 a_t + \mu_{it}$$

<sup>31</sup> In the generalised Cobb-Douglas (GCD) model, the elasticity of scale  $S$  is given by:

$$S_i = \frac{\sum \beta_i}{1 + \theta \cdot H_i}$$

where  $\lambda_i$  denotes the estimated coefficient for explanatory variable  $X_i$ . Similarly, input elasticities in the GCD are  $\lambda_i / (1 + \theta \cdot H_i)$ . This means that scale and input elasticities are computed at a particular data point (Greene, 1993: 327-28).

This model as a whole is intrinsically nonlinear due to the transformation of the variable  $H_{it}$  appearing on the left hand side of (4). Here,  $q$  is a parameter that varies between 0 and 1. The fact that  $\theta > 0$  allows us to test the possibility that the economies of scale decline as harvesting scales increase (so that to obtain an U-shaped average cost curve). To estimate the full set of parameters, we can scan over the range of  $\theta$  values, using least squares for different  $\theta$  values. The desired estimates are those that maximize the log-likelihood function or minimize Schwarz's Bayesian information criterion (B.I.C.). Table 4 shows the results for different  $\theta$  values.

TABLE 4  
GENERALIZED COBB-DOUGLAS (GCD) MODEL

Explanatory Variable	$\theta=0$		$\theta=10^{-5}$		$\theta=0.5$		$\theta=1$	
	S1	S2	S1	S2	S1	S2	S1	S2
$z_i$	0.86 (12.81)	1.20 (24.66)	0.94 (13.10)	1.37 (19.26)	4183 (10.8)	8616 (5.7)	8366 (10.8)	17230 (5.7)
$b(-1)$	0.95 (8.65)	0.53 (10.78)	1.10 (8.92)	0.68 (10.72)	7534 (8.8)	7440 (9.5)	15067 (8.8)	14880 (9.5)
$a$	1.35 (5.97)	0.63 (5.52)	1.57 (6.28)	0.91 (6.27)	11119 (7.1)	14453 (7.4)	22236 (7.1)	28906 (7.4)
D.W.	1.89		1.90		1.91		1.91	
F	59.73		54.28		24.62		24.62	
$R^2$	0.90		0.89		0.79		0.79	
LogL	273.38		109.08		-7,286.92		-7,835.87	
B.I.C.	-2.62		-2.20		16.47		17.86	

Note: t-statistics in parentheses,  $n$  is the number of observations,  $\log L$  is the logarithm of the likelihood function, D.W. the Durbin-Watson statistic, F is Fisher's statistic and B.I.C. is Schwarz's Bayesian information criterion. S1: vessels ( $N=22$ ) with Storage Capacity (SC) between 130 and 179  $m^3$ ; vessels ( $N=69$ ) with SC between 230 and 380  $m^3$ .

In the literature of nonlinear models it is customary to use the B.I.C. statistic and select the model which minimizes this value. In our case this happens for  $\theta=0$ , which corresponds to the traditional Cobb-Douglas production function. Going from  $\theta=0$  to  $\theta=10^{-5}$  the log-likelihood drops significantly, while the B.I.C. statistic increases from -2.62 to -2.20. The latter may not appear to be significant. However, resorting to Montecarlo experiments conducted by Lütkepohl (1982), this level of differences in the B.I.C. statistic turns out to be significant. Hence, the traditional CD function is the preferred model. Moreover, if we compute the scale and input elasticities resulting from the GCD model, using the sample average of  $H_i$  in each subpanel S1 and S2, we obtain the values shown in Table 5.

For  $\theta=0$  and  $\theta=10^{-5}$  the resulting elasticity values within each subpanel are not much different. Indeed, the key relative (S1 vs. S2) results obtained with the traditional Cobb-Douglas function do not suffer qualitative variations with

$\theta=10^{-5}$ . Therefore, there seems to be a robust case for rejecting the generalized Cobb-Douglas function and, hence, the hypothesis that the elasticity of scale is inversely related to the level of output (for the vessel sizes considered by groups S1 and S2).

TABLE 5  
INPUT AND SCALE ELASTICITIES, GCD MODEL

Variable	$\theta=0$		$\theta=10^{-5}$		$\theta=10^{-3}$	
	S1	S2	S1	S2	S1	S2
$z_i$	0.86	1.2	0.87	1.17	1.05	1.02
$b(-1)$	0.95	0.53	1.02	0.58	1.82	0.85
$a$	1.35	0.62	1.45	0.78	2.69	1.64
Elasticity of Scale	3.16	2.35	3.35	2.53	5.57	3.52

#### *A Translog harvesting function*

It may be the case that the value of the elasticity of scale is positively related to output levels. To test for this possibility, we consider a Translog harvesting function. Bjorndal (1989) is an example where Cobb-Douglas and Translog, per vessel, harvesting functions are estimated for a pelagic species (North Sea herring). He obtains increasing returns for individual fishing effort, though the estimations do not consider aggregate effort as an explanatory variable (neither fish stock proxies). In Bjorndal's estimations, a traditional Cobb-Douglas function turns out to be the best fit for the data. In our case, the Translog model to be estimated is

$$(5) \quad h_{it} = k_i + \alpha_1 z_{it} + \alpha_2 b_{t-1} + \alpha_3 a_t + \alpha_4 z_{it}^2 + \alpha_5 b_{t-1}^2 + \alpha_6 a_t^2 + \alpha_7 z_{it} b_{t-1} \\ + \alpha_8 z_{it} a_t + \alpha_9 b_{t-1} a_t + \mu_{it}$$

The results appear in Table 6. Equation (5) was estimated using generalized least squares, making use of a White-heteroscedastic consistent covariance matrix. We also show the parsimonious version for the Translog function, after eliminating all non-significant coefficients, testing the latter with a succession of Wald tests. The criterion to prefer the parsimonious model over the general one is Schwarz's B.I.C. statistic which, according to the Montecarlo experiments developed by Sawa (1978) and Lütkepohl (1982), is robust in its capacity to discriminate between models with similar values of this statistic; hence the parsimonious Translog model is also superior to the Cobb-Douglas one, the latter being a nested model of the former.

To obtain the parsimonious model we used Hendry's general-to-specific principle (as in Davidson *et al.* 1978). A Wald test (chi-square value of 23.51 with a p-value of 0.074) was unable to reject the null that  $\alpha_4=\alpha_6=\alpha_7=\alpha_8=\alpha_9=0$ .

TABLE 6  
TRANSLOG HARVESTING FUNCTION

Explanatory Variable	General Model		Parsimonious Model	
	S1	S2	S1	S2
Minimum Intercept	-498.3 (-3.5)	-648.8 (-9.7)	-489.8 (-3.4)	-633.1 (-9.5)
Maximum Intercept	-497.3 (-3.5)	-648.2 (-9.7)	-488.8 (-3.4)	-632.5 (-9.5)
$z_i$	0.17 (0.02)	-1.58 (-0.22)	0.87 (13.45)	1.20 (24.57)
$b(-1)$	58.50 (3.33)	79.00 (10.17)	56.50 (3.20)	75.57 (9.32)
$a$	0.83 (1.69)	0.33 (1.60)	1.66 (6.78)	1.07 (9.65)
$z_i^2$	-0.09 (-1.45)	0.05 (1.95)	-	-
$b(-1)^2$	-1.79 (-3.29)	-2.45 (-10.11)	-1.70 (-3.14)	-2.30 (-9.26)
$a^2$	0.003 (0.03)	0.01 (0.12)	-	-
$z_i b(-1)$	0.06 (0.20)	0.18 (0.64)	-	-
$z_i a$	0.04 (0.07)	-0.03 (-0.12)	-	-
$ab(-1)$	0.03 (1.46)	0.04 (4.47)	-	-
D.W.	1.92		1.90	
F	61.57		66.68	
$R^2$	0.92		0.92	
n	792		792	
LogL	350.12		324.57	
B.I.C.	-2.66		-2.72	

Note: t-statistics in parentheses, n is the number of observations, log L is the logarithm of the likelihood function, D.W. the Durbin-Watson statistic, F is Fisher's statistic and B.I.C. is Schwarz's bayesian information criterion. S1: vessels (N=22) with Storage Capacity (SC) between 130 and 179 m<sup>3</sup>; S2: vessels (N=69) with SC between 230 and 380 m<sup>3</sup>.

It should be true that inputs' marginal product are positive (monotonicity property; Chung, 1994:141). If we represent a general n-input production function as  $H=f(X_1, \dots, X_n)$ , the Translog function is written as

$$(6) \quad \text{Log}H = \log a_0 + \sum_{i=1}^n a_i \log X_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} \log X_i \log X_j \quad (i, j = 1, \dots, n)$$

Since  $H > 0$  and  $X_i > 0$ , monotonicity depends on the qualitative nature of the parenthesized term in

$$(7) \quad \frac{\partial H}{\partial X_i} = \frac{H}{X_i} \left( a_i + \sum_j \beta_{ij} \text{Log} X_j \right) > 0$$

The term between parentheses corresponds to input  $i$ 's share of total harvest (denoted by  $S_i$ ). Note that  $S_i$  also corresponds to the catch elasticity of input  $i$ . The monotonicity condition can be stated as  $S_i > 0$  ( $i=1, \dots, n$ ). For subpanel S1 it turns out that all three marginal products are positive with a 95% significance. The same can be said for subpanel 2<sup>32</sup>. Given the range of catch and aggregate biomass levels which prevailed during the period in our estimation sample, the latter results confirm our previous finding that all three explanatory variables have a significant positive effect on per-vessel catch.

The parsimonious Translog model implies no qualitative change versus the effort elasticities estimated with the previous Cobb-Douglas model. Increasing returns in per vessel effort productivity are confirmed for the modal vessel size in group S2. Equally confirmed is the greater positive externality, from aggregate fishing effort, enjoyed by the group of smaller vessels. Furthermore, in the Translog model the null that all intercepts are equal is also rejected for both subpanels<sup>33</sup>. This confirms the existence of non-explicitly accounted for idiosyncratic differences between vessels.

A new feature emerges in the stock-sensitivity of per vessel catches. Figure 1 plots the biomass elasticities as a function of aggregate biomass levels implied by the parsimonious Translog model. The plot considers the range of aggregate biomass variation during the estimation period (Table 2). Figure 1 should be interpreted with caution. Input elasticities are local concepts, involving marginal changes; whilst the plotted range of biomass levels is far from involving only marginal changes. Despite implied uncertainties of the specific values involved, the result that catch's stock dependence is sensitive to fish stock levels should be considered a robust reading. Being consistent with marine biologists' theories (e.g., Csirke, 1988), equally robust should be the negative sign obtained for the relationship between the degree of catch's stock sensitivity and stock levels.

The ranking of the estimated biomass elasticities (for S1 and S2) in the Cobb-Douglas framework is consistent with the estimation results in the Translog model, though restricted to aggregate biomass levels varying between 9 to 15 million tons. approximately. However, stock-specific values for the biomass elasticities remain subject to some degree of uncertainty. In order to provide for more robust readings about stock-specific values for per vessel catch's stock sensitivity, one would probably need to introduce biologically-related structure

<sup>32</sup> The null that  $S_i = 0$  for  $i=(z, b, a)$  is rejected significantly with chi-square values of 24.7, 31.5, 41.9 respectively for subpanel S1. For subpanel S2, these values are respectively 48.6, 103.5 and 64.1.

<sup>33</sup> With a 5% error the null is rejected with F tests equal to 8.59 and 7.91 for subpanels S1 and S2 respectively.

into the estimation model. Being this an important research challenge, it escapes the scope of our current endeavor.

Let us turn our attention now to the issue of economies of scale in harvesting operations. Firstly, if the Translog harvesting technology has constant returns to scale, equation (6) should be homogeneous of degree one. The (simultaneous) conditions for this to happen, with three inputs ( $Z_{it}$ ,  $B_{t-1}$  and  $A_t$ ), are:

$$(8) \quad a_z + a_b + a_a = 1$$

$$(9) \quad (\beta_{zz} + \beta_{zb} + \beta_{za}) = (\beta_{bb} + \beta_{bz} + \beta_{ba}) = (\beta_{aa} + \beta_{az} + \beta_{ab}) = 0$$

$$(10) \quad \beta_{zz} + \beta_{bb} + \beta_{aa} + 2\beta_{zb} + 2\beta_{za} + 2\beta_{ba} = 0$$

For both groups S1 and S2 we reject the hypothesis of constant returns to scale with a 95% of significance<sup>34</sup>. Moreover, under a Translog technology we confirm our previous finding of economies of scale (i.e. elasticity of scale greater than one) in the harvesting operations of vessels in groups S1 and S2<sup>35</sup>. Furthermore, under the Translog technology we cannot reject the hypothesis that the economies of scale are *increasing* in output levels for vessels in groups S1 and S2<sup>36</sup>.

These findings as a whole provide robust and consistent evidence for incentives leading to increase vessel's fishing capacity, in order to take fuller advantage of the prevailing economies of scale in harvesting operations. For vessel owners who behave as price-takers in input and output markets (i.e. the expected dominant behavior), economies of scale imply declining average and marginal harvesting costs. For the range of vessel sizes where the latter feature remains valid, the implied private optimal fishing strategy would be either full use of fishing capacity, given technological and regulatory constraints, or pursue pulse fishing. The latter means a self-enforced transitory use of maximum fishing effort, combined with intermediate periods of fishing effort shutdown (Clark, 1976, chs. 5 and 8; Lewis and Schmalensee, 1979, 1982). This type of fishing strategy could eventually reduce the likelihood of fishing collapse (Peña, 1996b). However, positive *switching* costs (due to on/off shutdown decisions) can preclude the self-enforced private optimality of pulse fishing. Informal evidence suggests

<sup>34</sup> The null of constant returns to scale is rejected at a 95% significance with Wald tests (chi-square values) equal to 30.7 and 75.7 for subpanels S1 and S2 respectively.

<sup>35</sup> The null (simultaneously) tested was that LHS of equation (8) be greater than 1, LHS of (10) greater than zero, and  $[(z_{it})(\beta_{zz} + \beta_{zb} + \beta_{za}) + (\beta_{t-1})(\beta_{bb} + \beta_{bz} + \beta_{ba}) + (a_t)(\beta_{aa} + \beta_{az} + \beta_{ab})] > 0$  (using sample averages for  $z_{it}$ ,  $b_{t-1}$  and  $a_t$ , for subpanels S1 and S2 respectively).

<sup>36</sup> This hypothesis refers to the third condition in footnote 35. For smaller vessels the Wald test is  $W=10.1$  (chi-square value) with a p-value of 0.018, and for the larger vessels  $W=23.02$  with a p-value of 0.000 (all at 95% of significance). If we were working with a 99% of significance, this hypothesis would only be accepted for the larger vessels.

that the latter is probably the case for the pelagic fishery of Northern Chile<sup>37</sup>. We conjecture, therefore, that for vessels enjoying economies of scale in this fishery, as seems to be the case for vessels in groups S1 and S2 along the period studied, the privately optimal fishing strategy probably consists of using the maximum attainable fishing effort, as long as positive profits prevail.

## 6. FINAL DISCUSSION

### *Economies of scale*

We have found robust evidence of economies of scale in harvesting. In the fishery we have studied, this finding complements the often quoted proposition of economies of scale in the processing stages of fishing industries (e.g. Crutchfield and Pontecorvo, 1969; Munro, 1982). Our results also suggest that the sources of these economies of scale in harvesting may differ according to vessel size. For the smaller vessels in our sample, positive externalities from aggregate searching effort have the greatest relative weight for triggering declining harvesting costs. In the case of the larger vessels, the greatest relative weight is related to increasing returns in the use of per vessel fishing effort. We have argued that prevailing economies of scale in this fishery most probably imply an incentive to use the maximum attainable fishing effort (given technical and regulatory constraints), as long as positive profits can be made. Other things being equal, the latter makes fishery regulation a complex task, as declining unit harvesting costs reinforce the incentives (in addition to those resulting from common property) to by-pass catch controls or specific fishing effort regulations.

Why economies of scale in harvesting have not lead to a more massive substitution of the smaller vessels in this fishery by larger vessels with greater fishing effort capacity is an open question. Bjorndal (1989) proposes a similar question, given his finding of increasing returns in the use of per vessel fishing effort for the North Sea herring fishery. His answer recurs firstly to a proposal of learning effects in searching effort, for the different fishing seasons within a given year; secondly, he argues for a case of productive inefficiency as a result of closed season regulations.

The latter type of regulation has been used extensively in Northern Chile for the period studied. We agree with Bjorndal that seasonal closures, as well as other controls on fishing effort, can lead to productive inefficiencies and hence contribute to maintain fishing effort levels which do not minimize unit harvesting costs. Indeed, there exists a robust case for arguing that conservation objectives need to be traded-off, particularly in the case of multi-species pelagic fisheries

<sup>37</sup> Interviews with private fishing entrepreneurs. A key underlying issue are positive switching costs faced by fish reduction plants (e.g. costs of turning on and off heating furnaces).



which are subject to not well-understood cyclical variations and to a fishing effort from a non-specialized fleet, against allocative losses resulting from productive inefficiencies (Hannesson, 1996).

The previous argument, however, does not suffice to explain why smaller vessels in Northern Chile have not been substituted at a faster pace by vessels with greater fishing capacity. This is an important issue, as it is related to the permanence of too numerous insiders (smaller boats tend to be predominant among small fishing firms). Government's support to small-scale fishing, given equity/political considerations, may have contributed to slow down this type of technological substitution. A similar effect may have been triggered by industry traps resulting from the combination between capital-rationing on behalf of small-scale fishermen and their low level of human capital. Nonetheless, larger fishing firms, without these restrictions, also tend to maintain a proportion of relatively small boats in their fleets. A possible explanation for this may be related to our finding of significant search externalities. Indeed, in schooling fisheries the search for productive shoals is a crucial endeavor (e.g. Bjorndal, 1988, 1989). In this type of fisheries, it is the case that the chances of finding productive shoals are enhanced by a larger number of operating vessels, given a constant level of total fishing capacity. The validity of this statement becomes stronger as the fish patches are more randomly distributed. Another reason might be that the chances of undetected non-compliance with the existing fishing regulations may increase by operating with a larger fleet of vessels, as one would expect that the enforcement costs be positively correlated with the number of operating vessels.

A better coordination of search efforts with a more efficient internalization of *search externalities* could be another reason for understanding the not so uncommon feature of industrial concentration in pelagic fisheries, including concentration in harvesting sectors<sup>38</sup>. So far, not much attention has been devoted to issues of industrial structure in fisheries, with the possible exception of discussions over concentration in processing sectors and of monopsonistic effects on harvesters (e.g. Clark and Munro, 1980; Munro, 1982; Schworm, 1983; Stollery, 1987). This is a research topic in which further economic analysis can provide additional useful insights to policy issues in fisheries' management.

#### *Catch's stock dependence*

Given the available levels of aggregate biomass over the period studied, we have found robust evidence of statistically significant positive stock dependence

<sup>38</sup> Further analysis of this issue can be found in Peña (1996a) which describes cases of pelagic fisheries subject to industrial concentration, both in processing and harvesting sectors: the Peruvian anchovy fishery during the 1960s and early 1970s, and the Chilean (Northern and Southern) pelagic fisheries, mainly devoted to fish meal production, since the mid 1970s to current times. Manning (1997) and Peña (1998) also offer insights on the observed industrial concentration, at least since the early 1980s up to now, in the case of the Namibian pilchard fishery.

on per vessel catch. For the modal vessel size in this fishery, the resulting biomass elasticity is less than one. This confirms similar results obtained while studying other pelagic fisheries around the world (e.g. Csirke, 1988; Bjorndal and Conrad, 1987). The positive sign of this dependence implies an incentive to exit the fishery once fish stocks become scarcer, whilst the *relatively weak* degree of stock dependence found can lead to falling stocks which eventually may cause the fishery to collapse. This seems to have occurred in cases of fishing collapse in other pelagic fisheries around the world (e.g. Gulland, 1988). For the smaller vessels in our sample, exit incentives are reduced by the presence of positive externalities in searching efforts. Our Translog harvesting estimation also suggests an inverse relationship between the degree of catch's stock dependence and prevailing fish stock levels. This confirms the often proposed hypothesis of compensatory growth patterns for pelagic species (Gulland, 1988). However, the lack of biological structure in our model precludes us from offering a robust explanation of the stock levels at which compensatory effects might begin to predominate.

The finding of a positive catch's stock-dependence implies by itself a higher optimal fish stock level, versus the case of zero stock-dependence. Notice, however, this is an independent issue from management controversies related to the classical 'stock-recruitment dilemma', which is particularly valid for fish stocks that are highly sensitive to changes in environmental parameters, in which "it is difficult to establish that (fishing mortality induced) reductions in the adult stock will reduce recruitment...until the process has gone so far (without a sufficient reduction of total fishing effort) that recruitment is seriously affected" (Csirke, 1988:297). In case that prevailing stock levels did imply a positive dependence of recruitment with respect to the adult stock, this effect by itself would justify a reduction in the optimal level of fishing capacity (e.g. Clark *et al.* 1985). For pelagic fisheries, however, this is particularly difficult to prove, as shown successfully by fishing entrepreneurs in recent controversies concerning proposals of global catch quotas in Northern Chile (Peña, 1997).

For the moment, not much can be said to clarify this controversy, until more evidence referring to stock recruitment in this and other pelagic fisheries, is gathered. Ideally, this should be done by considering relevant inter-species relationships (e.g. sardine vs. anchovy) as well as the stochastic nature of environmental effects influencing these biological feedbacks. Agreement on the need for this is easy to find. However, the proper way to do it is quite a different matter. Unfortunately, the biology on pelagic species seems not to have advanced that much since the late 1970s (e.g. Saetersdal, 1980 and other related papers in the symposium on management of pelagic fisheries). Answers to this challenge depend heavily on marine-like and biological discussions on these issues.

*Multi-species pelagic fisheries*

Pelagic stocks are highly variable populations, often living within interdependent multi-species systems. Both features make the management of these fisheries a risky and quite complex endeavor. Clark (1985, ch.5) is a good introduction to the types of problems faced while attempting to build multi-species models. Complexity rapidly increases when attempting to consider effects due to stochastic environmental shocks. Clark (1985) ends his argument by concluding "Because of these and other complications, the management of multispecies fisheries will probably remain as much an art as a science" (p. 204).

Nonetheless, as Clark (1985) acknowledges, policy decisions need quantitative boundaries for assessing risk trade-offs which are often encountered in fisheries' administration. The solution seems to be to pursue simple simulation-like analyses (e.g., Charles, 1983), while attempting to improve knowledge on environmental effects. Ideally, one would like to focus on parameter-sensitivity analyses to assess the risks when facing a possible fishing collapse. In the case of Chile, as well as for other developing countries' fisheries, these issues clearly constitute an important pending challenge.

While scientific knowledge as for now remains inconclusive, it makes sense to treat economically similar species (as those interacting in the fishery under study) as equal ones, from the point of view of fishery administration (e.g. Kirkwood, 1982). The general impression among fishery specialists seems to be that species-specific catch quotas should always be reduced in the presence of uncertainty, although the fishing industry often seems to take the opposite view. In multi-species fisheries, this divergence seems to be related to different values assigned by each group to individual species. From a fishery manager's point of view, however, the key issue here should be related to the net costs<sup>39</sup> assigned to the different probabilities of facing a fishing collapse. This line of reasoning leads to assessing the costs of facing a fishing collapse as a key option value problem. Maintaining a given fish stock level implies an option value in terms of avoiding expected net costs associated with the occurrence of a fishing collapse. In some cases, a significant depletion of some fish stocks can be shown to be optimal, provided that funds from depreciating fishing assets are able to earn sufficiently higher risk-adjusted returns in other productive areas. The history of pelagic harvesting world-wide suggests that scientific knowledge on pelagic fisheries up to now reduces the option values which society assigns to the conservation of these species. Political priorities, through their budget decisions concerning fisheries, are the decision-making instances where these option values are ultimately assessed and traded-off against alternative investments.

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Deducting expected benefits which could be earned by investing elsewhere in alternative assets.

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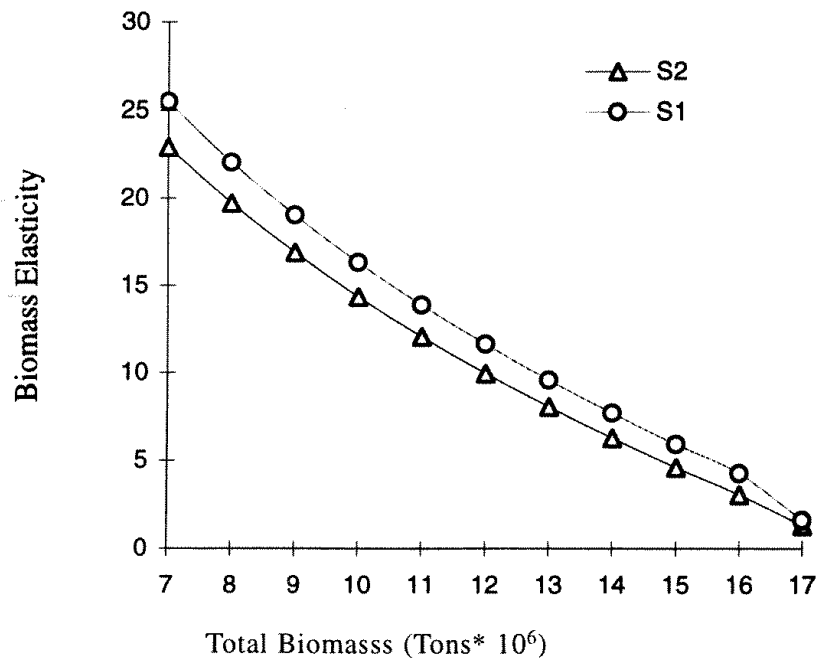
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<sup>39</sup> Deducting expected benefits which could be earned by investing elsewhere in alternative assets.

The understanding of relevant biological growth relationships for this fishery, as well as for others of a similar kind, is still a long way ahead and needs future research. There is ample room for making additional contributions to issues referring to relevant harvesting technologies and resulting fishing incentives. This paper attempts to contribute in this area. Possible extensions are related, in general, to improving our knowledge on technological choices, and the resulting fishing incentives, in this as well as other industrial fisheries. Our impression is that there is a lack of economic analysis in this area. Another extension could consist of an explicit differentiation between the main species being caught, attempting an improvement on the species-specificity and stock-level-sensitivity of the biomass elasticity estimations. The latter requires studying issues related to an expected (though still not well understood) correlation between anchovy and sardine stocks. A more exact measurement for fishing effort, considering individual trips' duration, would be useful for assessing the robustness of our findings of increasing returns from fishing effort for the modal vessel size. However, data restrictions precluded the analysis of this issue in this paper. Nonetheless, our finding of economies of scale in harvesting should prevail.

FIGURE 1: BIOMASS ELSTICITY (TRANSLOG MODEL)



## APPENDIX 1: AUGMENTED DICKEY-FULLER TESTS

Let  $x_{it}$  be any of the following variables (considering log transformation): per vessel harvest, aggregate fish stock, per vessel fishing effort (proxied by the number of fishing trips) and aggregate fishing effort. We estimate the following regression by least squares which includes both a constant and a temporal tendency

$$(a1) \quad \Delta x_{it} = \alpha + \beta t + \gamma x_{i,t-1} + \sum_{k=1}^n \delta_k \Delta x_{i,t-k} + \varepsilon_{it}$$

Here,  $\Delta x_{it} = (x_{it} - x_{i,t-1})$ ,  $i$  denoting the vessel and  $t$  the year;  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta_k$  are parameters that have to be estimated,  $\varepsilon_{it}$  are white noise errors, and  $n$  represents the minimum number of terms of the type  $\Delta x_{i,t-k}$  that have to appear in (a1) so that the error term is white noise.

The appropriate test is similar to the augmented Dickey-Fuller test (ADF). The usual  $t$  and  $F$  statistics are matched with critical values established numerically via Montecarlo simulations (Abuaf and Jorion, 1990). In expression (a1), parameter  $\gamma$  measures possible stochastic non-stationarity of  $x_{it}$ , whereas coefficient  $\beta$  measures the deterministic non-stationarity or tendency of such a variable. Table A1 shows the results of the pseudo-ADF test for each of our estimation variables.

TABLE A1: ADF TESTS

Variable	$\beta$	$\gamma$	$\bar{R}^2$	DW	F	N
Log $Z_{it}$	-3.3	-5.1 (0.0004)	0.14	2.1	15.5	176
Log $H_{it}$	3.5	-7.1 (0.0000)	0.22	2.1	25.4	176
Log $B_t$	-20.6	-36.6 (0.0000)	0.89	2.3	711.8	176
Log $A_t$	-10.0	-20.7 (0.0000)	0.72	2.3	227.9	176

Note: The null hypothesis to be verified are: (i)  $\gamma \geq 0$ , which means that variable  $x$  in (a1) is stochastically non-stationary, and (ii)  $\beta = 0$  which means that there is no tendency. The coefficients corresponding to  $\beta$  and  $\gamma$  are the normal  $t$  statistics, which are matched against the critical values of Abuaf and Jorion. The figures in parentheses correspond to the  $p$  values of these tests.  $\bar{R}^2$  is the adjusted  $R^2$  coefficient; DW is the Durbin Watson statistic,  $F$  the Fisher statistic, and  $n$  the number of observations.

APPENDIX 2: ANNUAL HARVESTS AND FISHING TRIPS  
(ESTIMATION SAMPLE)

Years	Annual harvest per vessel (tons, 10 <sup>3</sup> )				Annual fishing trips per vessel (number of trips)			
	mean	st.dv.	min.	max.	mean	st. dv.	min.	max.
1985 S1	11.3	3.5	4.1	17.1	153	41.4	59	214
S2	25.6	6.1	7.5	38.0	150	27.5	66	198
1986 S1	15.87	4.3	3.3	21.2	199	40.2	56	242
S2	25.18	6.5	11.5	36.3	168	25.7	104	205
1987 S1	6.66	2.1	1.3	9.8	161	47.9	34	206
S2	16.84	3.9	8.2	25.9	163	23.5	102	203
1988 S1	7.54	2.9	1.2	13.1	148	44.4	17	187
S2	16.84	3.2	10.5	23.2	144	14.2	105	181
1989 S1	8.63	2.8	0.8	13.9	152	41.1	17	196
S2	20.11	4.2	11.5	31.2	155	17.6	113	185
1990 S1	4.95	1.9	1.3	9.0	126	43.3	28	176
S2	10.93	2.5	5.5	18.1	125	22.7	51	166
1991 S1	4.59	2.2	1.7	10.0	132	57.5	39	230
S2	10.68	3.9	0.3	19.7	131	42.1	6	194
1992 S1	5.82	2.1	1.2	9.9	141	66.1	21	188
S2	13.63	4.2	1.8	20.9	147	36.2	26	198
1993 S1	4.52	2.3	1.7	11.5	105	50.2	28	211
S2	13.09	4.6	0.9	21.3	153	42.4	17	202

Source: Own calculations based on IFOP's statistics. S1: vessels with SC:130-179m<sup>3</sup>; S2: vessels with SC:230-380m<sup>3</sup>.

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