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FISH STOCK ENDOGENEITY IN A HARVEST FUNCTION: 'EL NIÑO' EFFECTS ON THE CHILEAN JACK MACKEREL FISHERY*

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Abstract

There are several examples of pelagic fisheries that have experienced fishing collapse when facing downward abundance cycles. Improving understanding about pelagic catch's stock dependence can help avoid new cases of fishing collapse. This paper analyses the possible endogeneity of the fish stock variable in a pelagic fishery harvest function. The harvest function is estimated using panel data and 'El Niño' episodes as instrumental variable for the Chilean jack mackerel biomass. This strategy produces consistent estimates of the fish biomass coefficient. The paper makes two

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contributions. First, it corrects for endogeneity of the fish stock variable, an issue often underestimated in empirical fishery economics. Secondly, it shows that 'El Niño' episodes have negative effects on the Chilean jack mackerel biomass.

Keywords: *'El Niño' Phenomenon, Endogenous Biomass in a Harvest Function, Instrumental Variable Estimation, Pelagic Fisheries.*

JEL Classification: *Q22, C33, L79.*

I. Introduction

This paper focuses on analysing the effects of fish stock changes on catch yields. In particular, it analyses the possible endogeneity of the fish stock variable in a harvest function. This is an issue often underestimated in the empirical literature on fishery economics. The case analysed is the Chilean central-southern jack mackerel (*Trachurus symmetricus murphyi*) pelagic fishery, which is described in Section II.

To analyse the relationship between catch yields and fish stock levels is equivalent to studying the stock dependence of vessels' catch per unit of effort. A lower (higher) stock dependence of catch per unit of effort tends to increase (reduce) the risk of fishing collapse. A weak 'stock dependence' is another way of referring to a weak "marginal stock effect" (Clark, 1976). A weaker (stronger) "marginal stock effect" tends to imply, *ceteris paribus*, a stronger (weaker) positive correlation between discount rates and fish stock depletion levels.

In the case of small pelagic fish stocks, they usually provide for high catch yields. This is related to the fact that small pelagic fish dwell at relatively low depths and move about and migrate in large and dense schools. In the fishery here analysed this characteristic is reinforced by the high fishing productivity that is associated with the Humboldt Current. Given this particular combination of features, different pelagic fisheries around the world have experienced problems of fishing collapse. Well known examples in the 20th century are the sardine fishery in Japan during the early 1940s, the sardine fishery in California a decade later, the herring population in the North Sea at the end of the 1960s and early 1970s, and the collapse of the anchovy fishery in Peru during 1972-73.

Therefore, analysing the feature of catch's stock-dependence is particularly relevant for the case of small pelagic fish stocks. It is frequently assumed that the schooling behavior of pelagic fish implies unit harvesting costs tending to be stock independent (except for 'very low' stock levels; Clark, 1982), which increases the stock's vulnerability to fishing effort. In the extreme case of no stock dependence, the literature speaks of 'pure' schooling behavior (Bjorndal, 1988, 1989). In a more general case, pelagic fisheries have often been described as implying catches with 'weak' stock dependence (Clark, 1982; Csirke, 1988). The latter has been interpreted as implying a catch-to-biomass elasticity that is positive but lower than one (Hannesson, 1983).

With respect to empirical evidence on these subjects, there are some studies that consider econometric estimations of harvesting functions for pelagic fisheries in the Northern hemisphere. Results with positive values are predominant for the catch to fish stock elasticity, though they are usually lower than the unit value. This is the case of results obtained for a herring fishery in the North Sea (Bjorndal and Conrad, 1987), as well as for the anchovy fishery in California (Opsomer and Conrad, 1994). Other studies have performed econometric estimation of harvest functions for pelagic fish (North Sea herring fishery) by assuming total independence between harvest levels and fish abundance (e.g. Bjorndal, 1988, 1989). All the studies cited in this paragraph consider Cobb-Douglas harvest functions and perform ordinary least squares (OLS) estimations. Additionally, all the studies here cited perform analysis about the statistical correlation between catch yields (in terms of caught fish weight) and a one-dimensional measure of fish stock's abundance, i.e. an estimate of the stock's total (aggregated) weight (adding up across different age cohorts).

Previous econometric studies about the Chilean central southern pelagic fishery (e.g., Peña-Torres *et al.*, 2003, 2004) have obtained positive and statistically significant values for (average period) point estimates of the catch to fish stock elasticity. However, these estimates have been obtained by performing OLS estimations, without implementing a convincing solution to the issue of biomass endogeneity.[1] The analysis in this paper explores new routes for tackling the issue of biomass endogeneity when estimating a fishery harvesting function. Specifically, we estimate a harvest function for the Chilean central-southern jack mackerel fishery using environmental shocks (corresponding to the 'El Niño' phenomenon) as instrumental variables for fish stock levels. In doing so, we explore the effects of the 'El Niño' phenomenon[2] on the jack mackerel stock levels, about which little is known.

The paper is organised as follows. Section II describes the fishery under study. Section III presents basic assumptions in our modelling of the harvest function. Section IV describes the data used. Sections V and VI report and discuss the estimation results. Finally, Section VII offers concluding remarks.

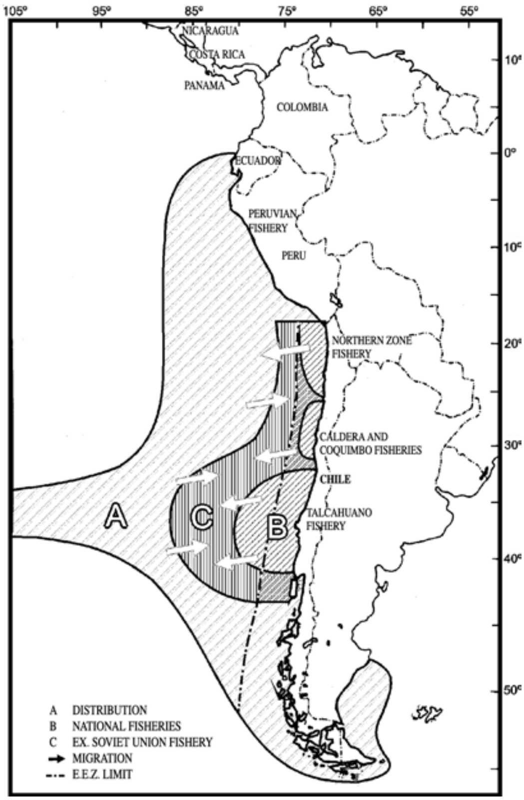
II. The Chilean Central-Southern Pelagic Fishery

This fishery runs along the central-southern coastline of Chile, starting at the port of San Antonio in central Chile and extending southwards to the Valdivia region, a distance of about 1000 km, with fishing effort centered on the Talcahuano region (Figure 1).

The Chilean central-southern jack mackerel fishery is part of a large oceanic distribution of jack mackerel stocks in the southeast Pacific (Figure 1, area A). Following a colonization process that began in the early 1970s, jack mackerel today extends into the southeast Pacific as far as 1000 nm off the coasts of Central Chile (along the Subtropical Convergence, around 40°S, reaching New Zealand and Tasmanian waters) (Serra 1991; Elizarov *et al*. 1993).

FIGURE 1

SPATIAL DISTRIBUTION OF JACK MACKEREL STOCKS IN THE SOUTHEAST PACIFIC



Source: Chilean Institute of Fisheries Research (IFOP).

The so-called Chilean jack mackerel stock, distributed within Chilean waters and in the adjacent high seas, reaching in some areas to about 110ºW, is believed to be a self-sustaining stock (Serra, 1991). Evseenko (1987) suggested the existence of an oceanic stock, beyond 120ºW and along the Subtropical Convergence reaching to New Zealand and Tasmanian waters, but it is as yet a pending question whether the oceanic stock is self-sustaining or needs inputs from the Chilean stock to persist.[3]

Off Chilean coasts, the jack mackerel is caught in four main fishing grounds (see Figure 1): a northern fishery, covering from the Chilean/Peruvian border (18°20'S) up to the Antofagasta area; a north-center or Coquimbo fishery; a central-southern fishery which is off the Talcahuano region (35°S-38°S) and extends southerly up to 43°-46°S; and an international fishery in high-seas adjacent to the Chilean EEZ. Since the mid 1980s, a predominant proportion of Chilean jack mackerel landings have been caught at the central-southern fishery. During the year 2004, landings obtained at the Talcahuano fishery represented 82 per cent of Chilean total commercial landings of jack mackerel.

Along its history, Chilean owned purse seiners have mostly exploited this fishery. However, during the 1980s a fleet composed of vessels from Poland, Cuba and Russia fished jack mackerel in the high seas off Central Chile (as well as in other high seas areas of the southeast Pacific).[4]

Industrial fishing is concentrated on pelagic species, primarily destined for the fishmeal industry. Although in its early industrial development the main species harvested in this fishery were anchovy (*Engraulis ringens*) and sardine (*Clupea bentincki*), since the beginning of the 1980s jack mackerel has become the dominant species for industrial vessels. Industrial landings of jack mackerel represented 82 per cent of total industrial landings during the period 1985-2002 (Table 1).[5] The Central-Southern pelagic fishery currently generates between US$ 200-250 million/year, in terms of export value and national sales. This value represents around 15-20 per cent of yearly exported values during the 2000s by the Chilean extractive fishing industry.

The early 1980s coincide with the starting of an intense investment phase (see Table 1). From 1980 to 1985 the number of industrial vessels doubled, while the fleet's hold capacity quadrupled. In the following decade the aggregate hold capacity again increased four times. This occurred at a moment when larger vessels began to increase their participation in the fleet (see Table 2). Aggregate annual haul of the fleet increased 6.5 times during the 1985-95 period. Annual haul is defined as the sum of the hold capacity for all operating industrial vessels, weighted by the respective hours the vessels spend fishing during each year. The concept of haul proxies the level of use assigned to the available aggregate fishing capacity.

The growth in annual harvest at this fishery continued uninterrupted until 1994-95 and has since declined. Catches of the three main species at year 2002 had declined to less than half the 1994-95 peak; jack mackerel catches have also declined by more than half.

The investment boom of the 1980s began under free access conditions, which prevailed from 1978 to 1986. From that point on, access regulations went into effect that 'froze' the fleet hold capacity to the limits it had in 1986. However, legal loopholes remained, allowing for further expansions of the fleet's fishing capacity (column 3 of Table 1). In practice, those loopholes allowed the entry of vessels with greater fishing capacity. Additional fishing licenses were also given to new vessels for starting fishing operations at the V and X regions. As a result, the total number of operating ships kept increasing up to the early 1990s (Table 1, column 2).

The number of operating boats started to decline since 1998. This result was affected by the systematic use of temporary fishing closures between November 1997 and December 2000. The fishing closures were part of a broader regulatory scheme called 'Research Fishing Trips' (RFT) Program, which in the central-southern region

TABLE 1

CENTRAL-SOUTHERN PELAGIC FISHERY (FROM V TO X REGION)

Year	Industrial Fleet			Industrial fleet's Landings (10^6 tons)		Yearly Average Biomass (10^6 tons)	
	Fishing Effort (index) (1)	Number of Vessels (2)	Total Hold Capacity (10^3 m^3) (3)	Three Main Species (4)	Jack Mackerel (5)	Three Main Species (V-X regions) (6)	Jack Mackerel (national level) (7)
1975		37	4.3				2.23
1980		47	6.3				7.18
1985	100.0	97	28.4	0.953	0.854		15.19
1986	143.6	93	29.9	1.128	1.051		15.90
1987	156.5	93	33.2	1.528	1.341		15.85
1988	191.0	105	40.4	1.705	1.439		15.19
1989	236.4	108	50.5	2.001	1.677		16.08
1990	307.7	145	67.9	2.093	1.860	16.00	15.45
1991	362.9	179	84.4	2.870	2.331	15.60	13.71
1992	424.7	176	87.1	2.882	2.472	12.50	10.86
1993	462.2	171	95.5	2.618	2.392	12.08	10.25
1994	572.3	168	103.9	3.575	3.254	11.16	9.49
1995	674.7	179	117.8	4.021	3.732	9.46	8.03
1996	636.8	159	113.6	3.401	2.805	10.15	7.32
1997	741.9	177	133.3	2.947	2.533	9.84	6.83
1998	610.9	163	131.0	2.079	1.465	10.07	7.08
1999	595.3	161	131.1	2.550	1.082	8.94	6.71
2000	447.3	148	125.9	1.802	1.063	8.93	7.05
2001	310.6	107	102.3	1.548	1.215	10.29	6.61
2002	370.8	65	70.3	1.400	1.142	9.94	6.48

(1) Total annual haul of industrial fleet (annual fishing hours multiplied by hold capacity), including all vessels operating at each year; (2) Total number of operating industrial vessels at each year; (3) Industrial fleet's total hold capacity (thousand m^3); (4) Industrial fleet's annual landings (three main species: common sardine, anchovy and jack mackerel); (6) and (7): Yearly average biomass (recruits and older age cohorts, in million of tons) estimated by the Chilean Fisheries Research Institute (IFOP). Column (6) refers to estimates for the Central-Southern zone, while column (7) refers to estimates at the national level (within Chile's EEZ).

Sources: IFOP and Sernapesca's Annual Fisheries Annals.

was exclusively applied to the jack mackerel fishery. Under the RFT Program, and when fishing effort was permitted, the fishery regulator and boat owners jointly decided which particular vessels would be allowed to operate at the jack mackerel fishery. Each of the chosen vessels had to prospect a specific marine area in order to collect catch sampling information to be used for fish stock assessment purposes.[6] Resulting catches could then be commercialised by boat owners, subject to complying with (ex-ante defined) per-vessel catch quotas. In practice, this regulatory scheme corresponded to a *de facto* individual vessel (non-transferable) catch quota system (Peña-Torres, 1997, 2002).

TABLE 2

NUMBER OF OPERATING VESSELS AT THE CENTRAL-SOUTHERN PELAGIC FISHERY
(Estimation Sample)

Year	Small (80-300 m^3)	Medium (301-800 m^3)	Large (> 801 m^3)	Total
1985	52	38	2	92
1986	47	44	2	93
1987	42	49	2	93
1988	40	62	3	105
1989	31	66	11	108
1990	50	74	21	145
1991	55	101	23	179
1992	54	94	28	176
1993	40	90	41	171
1994	30	87	51	168
1995	27	92	60	179
1996	22	73	64	159
1997	22	79	76	177
1998	16	70	77	163
1999	14	70	77	161
2000	9	63	76	148
2001	4	34	68	106
2002	2	10	53	65
Total vessels*				283

*: Number of different vessels that fished for at least one year during 1985-2002.

Source: Authors elaboration based on IFOP data.

As a parallel development, towards the end of year 2000 a protracted process of political negotiations finally succeeded in enacting important amendments to the Chilean Fisheries Law (Peña-Torres, 2002). The resulting new Fisheries Law formally introduced, since February 2001, the use of individual catch quotas into the main industrial fisheries of Chile, including the case under analysis.

Annual Total Allowable Catch (TAC) assigned to industrial fleets (for each fishery unit[7]) were divided into individual catch quotas (per boat owner), defined in tons. The initial quota allocations were given free of charge and had validity until December 2002. A new legal reform (Fisheries Law 19.849, December 2002) extended the validity of the individual quota system until year 2012. The assigned catch quotas 'per se' cannot be sold to another fisherman. The quota right is legally linked, in an indissoluble manner, to vessel ownership. Hence, transferability of quota ownership can only occur by simultaneously transferring vessel ownership. However, 'operational' quota-transferability does prevail in the sense that different boat owners can associate among themselves, with the exclusive purpose of performing fishing operations, in order to decide on which specific vessels they will jointly use (for fishing) the whole set of quotas assigned to them.

The introduction of individual catch quotas into the central-southern fishery quickly produced significant operational adjustments. The number of operating vessels declined rapidly and significantly (column 2, Table 1);[8] a similar trend can be observed in terms of the total hold capacity that was being mobilised by the industrial fleet in operation.

III. Modelling the Harvest Function

Our main interest consists in estimating the parameters of the harvest function for jack mackerel and, particularly, the effects of biomass on catch. For this purpose, we need to analyse, firstly, the possible endogeneity of the biomass variable to be used as control for changes in fish stock abundance; and secondly, if this endogeneity problem proved to be relevant, to discuss which biases could be introduced into the estimates of the catch-to-biomass coefficient.

Given these priorities, we choose a simple and parsimonious functional form for estimating the harvest technology. Firstly, we consider a Cobb-Douglas functional form which assumes that catch-input elasticities correspond to constant values; i.e., independent of the scale of fishing operations or the level of fish stock scarcity.[9] This simpler catch technology allows the analysis to focus more straightforwardly on testing the priority issue at this paper; i.e., the possible endogeneity of the fish biomass variable.

Secondly, we measure harvest output by focusing exclusively on jack mackerel landings, which is the dominant caught species all along the period studied (on average representing about 90 per cent of per vessel total landings). A key motivation for following this strategy is due to data availability regarding good (statistical) quality as well as lengthy time series of biomass estimates for jack mackerel. Biomass estimates for the other main species caught at this fishery are available on shorter time series. Moreover, expert assessments about the statistical quality of biomass estimates for the other main species are also less consensual.

Given our focusing on the catch-to-biomass coefficient, by estimating a single-species harvest function we also reduce risks of misspecification which could result from multi-species modelling; particularly in fishery contexts where inter-species biological interactions are still not well understood, as it is the case of the fishery analysed.

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

$$H_{it} = f(E_{it}, B_t, R_t, \alpha_i, \varepsilon_{it}; \beta) \tag{1}$$

where H_{it} denotes annual tonnage harvested by vessel i in year t, E_{it} is vessel i's use of variable inputs ('fishing effort'), B_t is fish stocks' availability, R_t a dummy variable for regulatory shocks, α_i is a control for vessel-idiosyncratic as well as time invariant features (denoted in the econometric literature as 'unobserved heterogeneity') which affect vessel catch yields per unit of variable fishing effort, ε_{it} is a residual term which encapsulates random (natural and man-originated) events affecting the harvesting success of vessel i in year t, and β represents a vector of parameters to be estimated.

The strategy of collapsing variable input choices into a single variable has well-established roots in fishery economics, resting on the plausible assumption that input ratios tend to be relatively fixed in fishing operations (for short- and medium-term decisions). E_{it} is expected to be positively associated with H_{it}. However, per vessel harvesting is also conditioned by fixed investment in vessel's fishing capacity. This is a multi-attribute variable. Searching technology (sonar, airplane's support), engine power, fishing gears, storage capacity, and captain's idiosyncratic knowledge are some of the fixed factors contributing to explain differences in vessels' catch success. Our sample does not contain enough information to explicitly consider all these attributes. However, one of the main advantages of using panel data is that it allows us to control for all the unobserved effects that are specific to each vessel.

Regarding the possible endogeneity of the fish stock (biomass) variable, there are two main reasons why the biomass variable could be endogenous in a harvest function. The first one is behavioral: catch affects biomass in a negative way, as the fish stock is being fished down over the annual season. The risk of biomass endogeneity could still be present in the case of using per vessel catch data, as long as there is a significant positive correlation between the catch yields of individual vessels over a given fishing season.

The second reason is statistical. Our biomass variable is calculated by the Chilean Institute for Fisheries Research (IFOP)[10] using Virtual Population Analysis. As we explain later, this methodology is based on the use of catch sampling data and therefore, by construction, the biomass estimates depend on catch volume as well as catch's age structure.

A feasible solution for an endogeneity problem is the use of instrumental variables. For this purpose we need to find a variable that is highly correlated with biomass and not correlated with the error term in the harvest function. Here we refer to partial correlation, i.e. a correlation between the instrument and the biomass variable, after all the other exogenous variables in the model are controlled for.

In this paper we perform instrumental variable estimation of the harvest function by using an oceanic measure of 'El Niño' phenomenon as a valid instrument for biomass. Later on we discuss about the validity of this assumption, given the particular measurement we use for instrumentalising the changes in biomass.

We consider an oceanic measure of the 'El Niño' phenomenon because of the jack mackerel stock's migratory patterns. Between August and February each year, corresponding to the spawning season of this species, the spawning stock migrates deep into the southeast Pacific. Although during this period the spawning stock achieves a wide North-South distribution, it has been reported that the main spawning area concentrates in front of the Chilean central-southern coastline, from 200 up to 1200 nm (Cubillos, 2003). Eggs and larvae remain in open seas areas until achieving juvenile status. Then juveniles start a migratory pattern travelling from West to East, entering the Chilean EEZ by its northern border. Here they first feed and grow and then start to migrate towards southern parts of the Chilean EEZ. Once the fishes achieve sexual maturity, at 2-3 years of age, the migratory pattern of the spawning stock is restarted.

As we explain in the next section, the variable biomass is measured with error. The effect of this measurement error, in the estimation of the harvest function, is to bias the coefficient of biomass towards zero (attenuation bias) and the coefficients of the other variables in unknown directions (Imbens and Hyslop, 2001). The use of instrumental variables for the biomass allows us to solve this problem too.

Our empirical approach then consists in estimating the harvest function with panel data and using episodes of 'El Niño' phenomenon as instrumental variable for the biomass variable (i.e., the stock's estimated aggregate weight). This strategy produces consistent estimates of the catch-to-biomass elasticity.

IV. Data

Our sample consists of a panel of industrial vessels operating in the central-southern region of Chile during the 1985-2002 period. There are 283 vessels in the sample, but the panel is unbalanced and the average number of observations per vessel is 7.9, with a minimum of 1 and a maximum of 18.

The data on the industrial fleet operation was obtained from IFOP. It includes per vessel annual data on: landed tonnage (different species); hold capacity (measured in m^3); annual operating hours off shore and vessel construction year.

In addition, we also obtained IFOP official estimates of jack mackerel's annual biomasses, covering the 1975-2003 period. We use this variable to control for fish stock levels in each year *t*. The biomass variable aggregates different age cohorts (adding them up in terms of weight) of a given fish stock, measuring the resulting biomass in tons. For annual estimation of jack mackerel biomass, IFOP uses Virtual Population Analysis (VPA) adjusted by an ADAPT procedure which uses complementary information obtained from hydro-acoustic surveys (Quinn and Deriso, 1999, pp. 352-33; Serra and Canales, 2002). The VPA method estimates the age distribution of a fish population on the basis of historical information on harvest age composition. Through backward extrapolation of the fish abundance (number of fish per cohort), together with assumptions on natural mortality and harvest rates, the population age distribution is estimated. This distribution is subsequently adjusted by cohort-specific average weights, from which the biomass estimations are finally derived. Therefore, by construction the biomass estimates depend on catch volume as well as the catch's age structure.

Table 3 shows the summary statistics of the data. Per vessel catch (denoted by 'Catch') is measured by the annual landings of jack mackerel for each vessel (measured in tons).[11] During the 1985-97 period (i.e., before the use of fishing ban regulations in this fishery) jack mackerel represented on average nearly 90 per cent of total industrial landings in the central-southern fishery. Consistently, our measure of fish stock availability focuses exclusively on biomass estimates for jack mackerel.

TABLE 3

DATA SUMMARY
(Estimation Sample)

Variable	N	Mean	Std. Desv.	Minimum	Maximum
Catch (*tons.*)	2,229	14,662.39	14,102.2	4.0	71,912.5
Biomass (*tons.*)	18	10,783,552	933,148	6,417,076	16,100,000
Effort (*hours*)	2,229	2,847.2	1,534.3	6.98	6,049.3
Vessel Age (*years*)	2,229	17.9	11.3	1	60
Research98	18	0.036	0.187	0	1
Research99	18	0.054	0.226	0	1
Research00	18	0.032	0.177	0	1
Niño1	18	0.61	0.5	0	1

In practice, however, the fleet under analysis performs multi-species harvesting. Apart from the three main species caught, there are other species which have minor participation in annual industrial landings at this fishery. Table 4 shows the three main species' average shares in total annual landings per industrial vessel. Considering years in which there were no direct regulations on fishing effort (i.e., excluding the 1998-2000 period when the RFT Program was in operation),[12] ships in the large size (≥801 m^3) category clearly specialize in fishing jack mackerel. This species also has a dominant proportion in the annual catch of vessels belonging to the 301-800m^3 size category. A key reason for this is that vessel's maneuvering capacity and search capabilities play a crucial role in finding high-yield fishing grounds for catching jack mackerel. By contrast, smaller ships (80-300m^3) tend to specialise on coastal fishing, operating in areas where sardine and anchovies are the predominant species. Hence, the latter species represent a higher proportion of total landings for vessels belonging to the 80-300m^3 size category.

The variable used for capturing the effects of fishing effort (denoted by 'Effort') is the annual number of total hours a vessel is off shore. It is a measure of actual fishing effort, including travelling time to the areas where the vessel fishes. This variable aims at proxying variable input use. Given the data available, we do not know the proportions of annual fishing efforts which are devoted to fishing different species.[13] Our measure of fishing effort covers all species caught. Hence, the latter feature does constrain the interpretations that can be given to estimations of the catch-to-effort elasticity.

The variable biomass is the annual average biomass of jack mackerel within Chilean waters,[14] which considers a larger area than just the central-southern part of the country where our sample of vessels was actually fishing. Therefore, the variable biomass is measured with error for the purpose of estimating a harvest function in the central-southern region of Chile.

Vessel age (denoted by 'Age') is measured in years and it is calculated as the difference between the current year and the construction year of each vessel. This variable

TABLE 4

MAIN SPECIES SHARES (YEARLY AVERAGE) IN TOTAL ANNUAL LANDING PER VESSEL
(Industrial Fleet, Period 1985-2002)

Vessel size category (m^3):	(1) Jack Mackerel		(2) Common Sardine		(3) Anchovy	
	1998-2000	Remaining years in period 1985-2002	1998-2000	Remaining years in period 1985-2002	1998-2000	Remaining years in period 1985-2002
80-300:						
Yearly Avg.	0.05	0.39	0.46	0.30	0.47	0.26
St. Dv.	0.06	0.31	0.24	0.26	0.29	0.23
301-800:						
Yearly Avg.	0.23	0.73	0.38	0.10	0.34	0.09
St. Dv.	0.12	0.26	0.12	0.15	0.11	0.13
≥801:						
YearlyAvg.	0.71	0.87	0.06	0.01	0.09	0.01
St. Dv.	0.11	0.09	0.05	0.03	0.08	0.04

Notes:

(a) The notation '0.71' means 71% of yearly average total landings per vessel, within a given vessel-size category; Avg. means average; 'St. Dv.' means standard deviation.

(b) Shares are calculated on the basis of average annual landings (species composition) per vessel, for the following vessel size categories: (Pl) 80-300 m^3; (P2) 301-800 m^3; (P3) ≥801 m^3.

controls for possible technological obsolescence as well as, in an undistinguishable manner, accumulated experience effects.

With the purpose of controlling for important regulatory changes occurring during the period of analysis, we consider two sets of dummy variables. Firstly, to control for the operation of the 'Research Fishing Trips' (RFT) Program, which was exclusively applied during the 1998-2000 period to jack mackerel catches in the central-southern pelagic fishery, we include dummy variables for 1998, 1999 and 2000 (denoted by 'Research98' and so on). The number of vessels involved in research fishing trips was 83 in 1998, 127 in 1999 and 74 in 2000. Overall, a total of 144 different industrial vessels made at least one research fishing trip over the 1998-2000 period.

Secondly, since 2001 the government introduced individual fishing quotas for the three main species caught at the central-southern pelagic fishery. This meant that for the first time TACs were formally introduced into this fishery.[15] To control for the effects of the quota system we included dummy variables for the years 2001 and 2002. The variables D2001 and D2002 are equal to one for the year 2001 and 2002 respectively, and zero otherwise.

As it was explained before, we use environmental shocks, corresponding to an oceanic measure of 'El Niño' episodes, to identify the effect of changes in biomass levels upon per vessel catch. Based on the definition used by the National Oceanic and Atmospheric Administration (NOAA, USA), an oceanic episode of 'El Niño' occurs when the Oceanic 'El Niño' Index (ONI) increases by at least 0.5°C above its historical level. ONI is a 3 month moving average of deviations in the sea surface temperature, relative to an historical level defined by the yearly average sea surface temperature for the period 1971-2000.[16] The variable Niño1$_t$ is then a dummy variable equal to one if there occurs an 'El Niño' episode during year *t* (i.e., if there is at least one 3-months average, within year *t*, in which the ONI is at least 0.5°C above its historical level) and zero otherwise.

In our estimations we also constructed and tested other variables for measuring 'El Niño' phenomenon. We constructed a Niño2 variable with the same dichotomic definition than Niño1, but now calculating its value by only considering 3-month moving averages corresponding to the spawning season (from October to February each year) of the jack mackerel stock. We also tested another variable which was aimed at controlling for the persistence (as well as the intensity) of 'El Niño' phenomenon. It was defined as equivalent to the number of 3-month moving averages, within each year *t*, with ONI values equal to or greater than +0.5 C°. From all these measures for the 'El Niño' phenomenon, Niño1 was the only one which consistently showed clear statistical significance and strong robustness in its sign of impact upon jack mackerel biomass. Therefore, we report here only the estimations obtained when using the Niño1 variable.

Finally, to control for other time effects which might have a monotonic influence upon vessel catch yields and which are not dependent on vessel-idiosyncratic conditions, we also include a trend variable. This variable might capture general technological innovations or changes in fishing productivity over time.

V. Results

Table 5A shows the fixed effects estimation of the following per vessel harvest function (all the variables, except the time trend (*T*) and dummy variables (*D* and *R*), are in logs):

$$Catch_{it} = \beta_0 + \beta_1 Biomass_t + \beta_2 Effort_{it} + \beta_3 Age_{it} + \beta_4 T_t + \sum_{j=1998}^{2000} \beta_j R_j + \sum_{j=2000}^{2001} \beta_j D_j \qquad (2)$$
$$+ \sum_{j=1998}^{2000} \beta_j R_j \cdot Effort_{it} + \alpha_i + \varepsilon_{it}$$

where the *βs* denote the coefficients to be estimated, α_i are the fixed effects, *T* is a trend variable, *Rs* denote the dummies associated to the RFT Program, *Ds* are the dummies associated to the individual catch quota regulation and ε_{it} denotes the residual estimation errors.

TABLE 5A

ANNUAL HARVEST FUNCTION
Dependent variable: ln (per vessel annual landed tonnage of jack mackerel)

Variable	Model 1 (OLS)	Model 2 (I.V.)	Model 3 (I.V.)	Model 4 (I.V.)
Constant	2.32	35.42	38.9	39.16
	(4.4732)	(8.1384)**	(6.5989)**	(7.399)**
Ln ($Biomass_t$)	−0.04	−1.99	−2.20	−2.21
	(0.2637)	(0.4794)**	(0.3895)**	(0.4355)**
Ln ($Effort_{it}$)	1.07	1.06	1.06	1.06
	(0.0476)**	(0.0397)**	(0.4053)**	(0.0404)**
Ln (Age_{it})	0.15	0.12	0.11	0.11
	(0.1056)*	(0.0802)	(0.0789)	(0.0796)
$Trend_t$	−0.17	−0.32	−0.34	−0.34
	(0.0250)**	(0.0394)**	(0.0327)**	(0.0357)**
Research98	1.31	1.29	1.29	1.29
	(0.3259)*	(0.5137)*	(0.5179)*	(0.5245)*
Research99	3.54	3.56	3.26	3.56
	(1.6336)*	(1.6205)*	(1.5492)*	(1.6261)*
Research2000	2.15	2.27	2.28	2.28
	(0.5700)*	(0.8054)*	(0.8129)*	(0.8522)*
D2001	0.82	1.22	1.27	1.27
	(0.1367)**	(0.1601)**	(0.1494)**	(0.1542)**
D2002	0.42	0.96	1.02	1.03
	(0.1395)*	(0.1833)**	(0.1637)**	(0.1718)**
Research98·ln ($Effort_{it}$)	−0.18	−0.16	−0.16	−0.16
	(0.0410)*	(0.0652)*	(0.0651)*	(0.0665)*
Research99·ln ($Effort_{it}$)	−0.52	−0.51	−0.50	−0.50
	(0.2059)	(0.2044)**	(0.1949)**	(0.2051)**
Research2000·ln ($Effort_{it}$)	−0.26	−0.22	−0.22	−0.22
	(0.0717)*	(0.1017)*	(0.1031)*	(0.1077)*
R2	0.8511	0.8526	0.8534	0.8529
F	144.08	150.12	152.9	151.36
N		2229		
Number of Vessels		283		
Average Obs. Per Vessel		7.9		
Max Obs. Per Vessel		18		
Min Obs. Per Vessel		1		

Values in parenthesis are robust (to heteroskedasticity and autocorrelation) standard errors.
*: Significant at 95% of confidence; **: Significant at 99% confidence.
OLS: Ordinary Least Squares; I.V.: Instrumental Variables.

Model (1) in the Table 5A was estimated using Ordinary Least Squares (OLS) just for comparisons to Models (2) through (4), which were estimated using Instrumental Variables. The instrumental variables estimation is based on a two stage least squares estimation. The first stage is a regression of Biomass on all the exogenous variables of the model plus the instrument. The second stage regression consists of estimating equation (2), but replacing the variable Biomass by the fitted values of Biomass from the first stage regression. The standard errors for all models were obtained using the robust asymptotic variance matrix estimator proposed by Arellano (1987). This estimator is valid in the presence of heteroskedasticity or serial correlation if T (number of time periods) is smaller than N (number of cross-sectional units), which is the case in our sample.

The main advantage of using fixed effects estimation is that the fixed effects capture all the unobserved fixed factors per vessel that may affect catch yields: search technologies, engine horse power, fishing gear, and fishing experience of the captain and the crew, supposing that all these factors remain fixed over the studied period. The fixed effects specification was confirmed by a Hausman test, which rejected the alternative random effects specification. The implication of this result is that the use of fixed effects produces consistent estimators of the parameters of equation (2), whereas the random effects specification does not.

The cost we pay for using fixed effects estimation, as opposed to random effects, is that we cannot identify the coefficient of any explanatory variable that does not change over time. In this particular case, we are not able to directly estimate the effects of different vessel sizes on the jack mackerel catch. Nevertheless, the fixed effects specification does control for the size of each vessel because this is a variable that does not change over time. Therefore, the estimation of equation (2) does not suffer from an omitted variable bias due to the lack of explicit controls for vessel size.

As can be seen from the table, in Model (1) the coefficient of Biomass is slightly negative, but statistically not different from zero. A potential interpretation for the non significance is that biomass may have no effect at all on jack mackerel catch. An alternative explanation is that the estimated coefficient of biomass could be biased. As it was discussed in Section III, we believe there is an endogeneity problem that biases the estimated catch-to-biomass elasticity.

In fact, a Hausman test (Hausman, 1978) rejects the exogeneity of the Biomass variable in the harvest function. Additionally, in the data we use there is measurement error in the biomass variable, which also biases the estimates. In the case of measurement error we know the direction of the bias: the estimated coefficient of the biomass will be biased toward zero due to attenuation bias (Greene, 2003). However, the use of valid instrumental variables solves both problems and provides consistent estimates of the biomass elasticity.

Model (2) estimates the same equations as Model (1) but using Niño1 as instrument for (contemporary) Biomass. The coefficient of Biomass is now negative, fifty times larger in absolute value than in model 1, and statistically significant. The estimated elasticity is -2 implying that, as average during the studied period, a one per cent increase in the jack mackerel biomass volume reduces the catch of individual vessels by two per cent.

As expected, fishing effort has a positive and statistically significant impact on catch volume. An increase of one per cent in the number of annual hours a vessel is off-shore is associated with a one per cent increase in the catch of jack mackerel. Recall that estimated coefficients in our case represent average values across time and across vessel size categories.

The coefficient of the Age variable is positive, but statistically not different from zero. We did not have a prior sign for this variable. The age of a vessel might capture its technological obsolescence, in which case the coefficient should be negative, and also some accumulated 'learning by doing' effects, in which case the coefficient should be positive. Therefore, a zero coefficient could be explained either because these two effects offset each other or because vessel's age actually has no effect on catch. The data we have does not allow us to distinguish between these two alternatives.

The linear trend has a negative and significant coefficient. The estimated negative sign could be capturing the fact that catch per unit of effort has been declining over time in this fishery, partly because fish resources are becoming scarcer (though the biomass variable is controlling for this effect) and also because traveling distance to productive fishing grounds has increased over time. There might be perhaps other explanations. Whatever be the case, the trend variable is statistically significant and therefore cannot just be dropped from the regression. Still, and as an additional robustness check of the results, we also run the same regressions without the time trend and the results were not qualitatively different.

The 'Research Fishing Trips' (RFT) dummies are all positive and statistically significant. We also included in the regression the RFT dummies interacted with effort because vessels participating in the RFT program had to follow a pre-assigned travelling/fishing path (which was specified by IFOP), as well as complying with per-vessel catch quotas when harvesting jack mackerel. Therefore, catch yields, targeted fishing grounds and fishing effort levels were all affected by vessel participation in the RFT program.

Evaluated at the mean value of the sample, the impact of participating in the RFT program was to increase at the margin the per vessel catch of jack mackerel by 0.1 per cent in 1998, reduce it by 0.3 per cent in 1999 and increase it by 0.6 per cent in 2000. Regarding the catch-to-fishing effort elasticity, its value changes from 1.06 (during the years in which there was no research fishing trips) to 0.9 in 1998, 0.55 in 1999 and 0.84 in 2000. Therefore, participation in the RFT program made marginal fishing hours less productive, though the RFT program did increase per vessel average catch of jack mackerel (compared with per vessel average yields during the 'Olympic race' period).

The dummies for the years 2000 and 2001 are also positive and significant, showing the positive impact that the introduction of individual catch quotas had on per vessel catch of jack mackerel. With individual catch quotas, companies are able to fully optimize the operational use of their vessels over the year. As a result, not only the number of operating vessels did rapidly and significantly decline but also the operating fleet became increasingly concentrated on vessels belonging to the large size (>801 m^3) category. Peña, Basch and Vergara (2003) have shown that large sized vessels operating at the central southern pelagic fishery on average obtain higher catch yields per unit of fishing effort, when compared with smaller vessels.

In addition to the contemporary Niño1 effect considered in the first-stage estimation, Model (3) also adds Niño1 with one year lag as instrument because an episode of 'El Niño' can affect the fish stock's biomass not only through contemporary effects but also over a longer period of time, given the transmission of El Niño effects through the biomass' age structure. The absolute value of the biomass coefficient in the harvest function (Model 3) is now slightly larger than in Model (2) and again it is negative and statistically significant. The point elasticity is now -2.2. Finally, Model (4) adds an additional annual lag of Nino1 as another instrument for biomass, given that recruitment occurs at two years old in the Chilean jack mackerel stock. The point elasticity is again -2.2 and statistically significant.

Table 5B reports the first-stage estimation results for the oceanic 'El Niño' variables which are used as instruments for biomass. Each of the three 'El Niño' variables consistently obtains a negative and statistically significant coefficient of impact upon biomass. According to Model 4, the contemporaneous impact of the 'El Niño', in a given year *t*, upon the Chilean jack mackerel biomass, is nearly doubled by the cumulative biomass effects which are observed one and two years later (and which are transmitted through the biomass' age structure).

TABLE 5B

FIRST-STAGE REGRESSIONS (FIXED-EFFECTS ESTIMATION)
Dependent Variable: $Ln(Biomass_t)$

Variable	Model 2	Model 3	Model 4
$Niño1_t$	−0.098 (0.0036)**	−0.097 (0.0033)**	−0.103 (0.0036)**
$Niño1_{t-1}$		−0.046 (0.0042)**	−0.046 (0.0039)**
$Niño1_{t-2}$			−0.046 (0.0023)**
R2	0.944	0.947	0.949
Test F	1704.66	2258.45	2408.95
Test F (overid test) (p-value)		0.29	0.57

Values in parenthesis are robust (to heteroskedasticity and autocorrelation) standard errors. Due to space restrictions, only the coefficients and standard errors of the instruments are presented in the table. However, the first-stage regressions also include all the exogenous variables in the harvest model.
**: Significant at 99% confidence.

The negative coefficient obtained for the ‘El Niño’ effects upon jack mackerel biomass is consistent with recent testing (Yepes, 2004) of the ‘El Niño’ effects upon the recruitment rate (number of recruits as proportion of the spawning biomass) of the Chilean jack mackerel stock. Yepes (2004) reports a negative and statistically significant coefficient of impact, of a dichotomic (and oceanic) measure of the ‘El Niño’, upon the recruitment rate of the Chilean jack mackerel stock.

Studies about other small shoaling pelagic fish have also reported a negative relationship between fish biomass levels and the occurrence of ‘El Niño’ phenomenon. Csirke (1980, 1988) describes a relationship of this type for the Peruvian anchovy. Quoting from Csirke (1988, p. 286-7):

> “…during the onset of the 1972-73 ‘El Niño’ phenomenon in the southeast Pacific, the northern and central stock of the Peruvian anchovy was compressed inshore and further south by the advance of the warm water front that reduced the area with water temperatures suitable for the anchovy shoals….This contributed to an increase in the catchability coefficient, …*while the recruitment (the main element of the natural productivity of the stock) was also sharply reduced*.” (Italics is ours).

Regarding the collapse of the Californian sardine fishery in the early 1950s, Cushing (1988, pp. 253) and Herrick *et al*. (2004) also quote different studies (Marr, 1960; Baumgartner *et al*., 2002; McFarlane *et al*., 2002; Chavez *et al*., 2003) which suggest a negative relationship between sardine recruitment success and environmental shocks.[17]

Table 6 reports the confidence intervals of the estimated catch-input elasticities for all models. The elasticities of effort and age do not vary much across models. In the case of effort, the elasticity is positive on the whole interval and it ranges between 0.98 and 1.17. In the case of age, an elasticity of zero falls within the interval which ranges between –0.05 and 0.36.

The confidence interval for the biomass elasticity includes zero and ranges between –0.56 and 0.48 when estimated with a fixed effects model without solving the endogeneity and measurement error biases. Once the latter two biases are eliminated with the use of instrumental variables, the confidence interval for the biomass elasticity

TABLE 6

ESTIMATED CATCH-INPUT ELASTICITIES
Confidence Intervals (at 95%)

Variable	Model 1	Model 2	Model 3	Model 4
$Biomass_t$	–0.56; 0.48	–2.93; –1.05	–2.97; –1.44	–3.02; –1.41
$Effort_{it}$	0.98; 1.17	0.98; 1.14	0.98; 1.14	0.99; 1.14
Age_{it}	–0.05; 0.36	–0.04; 0.28	–0.04; 0.27	–0.04; 0.27

only includes values which are consistently negative over the whole range. Therefore, the endogeneity of the biomass variable biases upwardly the magnitude of its coefficient in the Cobb-Douglas harvest function. In the case of our data, the endogeneity problem can even change the sign of the catch-to-biomass coefficient.

As it usually happens with the use of instrumental variables, the estimation results finally hinge on the assumption that the instruments are not correlated with the error term in the harvest function. This assumption cannot be tested. However, when more instruments than needed to identify an equation are available, it is possible to test whether the additional instruments are valid in the sense that they are uncorrelated with the error term in the structural equation. The last row of Table 5B shows the results of testing these overidentifying restrictions. As it can be seen from the table, in all cases we cannot reject, at any reasonable confidence level, the null hypothesis that the instruments are valid.

VI. Discussion

Once we have corrected for the endogeneity problem, why are we obtaining a negative value for the catch-to-biomass coefficient? Firstly, it is worth remembering that the estimated coefficient refers to a ‘partial correlation value’ between jack mackerel’s per-vessel catch and biomass *levels* (both measured in tons). Secondly, the estimated coefficient corresponds to an ‘average impact value’ for the overall sample period (1985-2002). Now, all along this period changes in different biological, ecosystem as well as fleet-related mechanisms could be affecting the estimation results. Biological and ecosystem-related mechanisms could be producing changes not only in biomass abundance (total number of individuals) but also in the fish stock’s density and spatial distribution. Moreover, all these changes could also be affecting natural growth, mortality and recruitment rates (and through them, triggering changes in fish stock’s age structure). Other ecosystem-related mechanisms could be linked to environmental shocks, for example changes in food availability or temperature-related changes in somatic growth.

Regarding the case of the Chilean jack mackerel stock, we are not aware of conclusive scientific knowledge that could help identify the specific nature of relevant underlying biological and ecosystem-related mechanisms as those referred to in the previous paragraph. Nonetheless, it is clear that some important biomass-related changes have indeed occurred along the period analysed at this fishery.

Firstly, since the early 1990s, and up to the end of the sample period, jack mackerel biomass levels have been monotonically declining: at year 2002 total biomass was only 40 per cent of its peak estimated levels during the second half of the 1980s (see Table 1). By contrast, before years 1990-91, and from the beginning of the sample period, biomass levels were monotonically increasing. A similar evolution (first an increasing trend, then a declining one) is observed in the yearly tonnage landed by the industrial fleet in this fishery (being year 1995 the turning point in the landing trend). Secondly, in terms of changes in the fish stock’s age structure, all along the second half of the 1990s the Chilean jack mackerel stock did experience an increasing juvenilization process, which started to being partially reverted only from years 2002-03 onwards (as a result, among other factors, of binding catch quotas). A third important change is the increasing evidence suggesting that the Chilean jack mackerel's spatial distribution has moved southwards and further into open seas,[18] particularly since the late 1900s and early 2000s (Barria *et al.*, 2002; Subpesca, 2004; Valderrama, 2006). As a consequence, since the early 2000s the Chilean industrial fleet has been extending its fishing grounds up to 600-700 nm from the coastline. Finally, in terms of trends in the resulting catch's species mixture, during the second half of the 1990s there is also a decline in the jack mackerel share in total industrial landings (in favour of sardine and anchovy landings). However, the bulk of this effect did occur during the 1998-2000 period and so it has been controlled for in our estimation models by the 'RFT Program' dummies.

Whatever be the specific combination of underlying mechanisms, the negative relationship found between per vessel catch and biomass levels should be interpreted as a negative relationship (averaged for the whole sample period) between the catchability coefficient (denote it by q) and the biomass level. The catchability coefficient is defined as $q_t \cdot B_t = (H_t/E_t)$, where H_t is the catch at period t, E the fishing effort and B the fish biomass.

Csirke (1988, p. 289) cites diverse studies, for different *pelagic* fisheries, where the estimated values for q vary inversely with B. In the case of a Cobb-Douglas harvest function that includes fish biomass as one of its regressors, and considering a relationship such as $q=a \cdot B^{\gamma}$, a negative value of γ would imply, all the rest being constant, a lower estimated value for the biomass coefficient (versus the case of γ being non negative).

Related to the possibility of γ being negative in the case of *pelagic* fish, a frequently cited hypothesis in marine biology is that when pelagic fish abundance falls, the stock reduces the range of its feeding and breeding areas, with concurrent decreases in the number of schools, though the average size of each school tends to remain constant. In this case, the fish stock reduces the range of its spatial distribution while simultaneously increasing its density. The expected result is an increase in 'catch yields per unit of fishing effort'. As Csirke (1988, p. 274) has described it: "if the (pelagic) stock is falling, the true fishing mortality may stay high, or even increase."

Another hypothesis related to *pelagic fish*, in particular to the case of Pacific sardine, and which also helps illustrate the possibility of q being inversely related to B –though now referring to effects directly triggered by changes in sea temperature, can be cited from Clark and Marr (1955). These authors have suggested that schools of sardine become denser and contain more fish at lower water temperatures than they do at higher temperatures, implying that catch might indeed increase with a decline in water temperature (while the latter change also produces a fall in sardine biomass).

VII. Concluding Remarks

A first important result from this paper is the suggestion that 'biomass endogeneity' could be a relevant problem when a biomass proxy, especially when it coincides with a biomass VPA estimate, is used as explanatory variable in a yearly harvest function. In the specific case of the data available for the Chilean jack mackerel fishery, we also faced a measurement error in the biomass variable which biases towards zero (attenuation bias) the estimate of the biomass coefficient. In this modelling context, an OLS estimation of the harvest function produces inconsistent estimates of its coefficients.

Indeed, when a Cobb Douglas harvest function was estimated by OLS, but without correcting for endogeneity and measurement error problems, we obtained a positive (though not significant) coefficient for biomass. Once the endogeneity and attenuation biases were dealt with by using instrumental variables, the biomass elasticity became persistently negative and statistically significant. It is important to highlight that these coefficients, estimated by fixed effects while simultaneously using valid instrumental variables, are consistent. Additionally, the standard errors, estimated by using the asymptotic variance matrix estimator proposed by Arellano (1987), are robust to heteroskedasticity and autocorrelation. Therefore, as long as the *Niño1* variables are valid instruments for jack mackerel biomass, the endogeneity of the VPA biomass variable biases upwardly the magnitude of its coefficient in a Cobb-Douglas harvest function. In the case of our data, the endogeneity problem even changes the sign of the catch-to-biomass elasticity.

Regarding the specific (and surprising) result of the negative sign obtained for the catch-to-biomass elasticity, two further comments should be made. Firstly, as we have already discussed, the negative biomass elasticity could be potentially explained by different underlying biological as well ecosystem-related mechanisms. However, as it is always the case when using instrumental variables, the estimated negative biomass coefficient could also be the result of using invalid instruments. Nonetheless, in our case (i.e., with over-identifying instruments) we cannot reject the null hypothesis that the instruments used are valid. Even though, it would be valuable to explore the use of alternative valid instruments to confirm our results. Secondly, it would also be a valuable testing to analyse the possibility of a 'structural break' in the sample data occurring around the late 1980s and up to the first years of the 1990s. An important turning point did occur somewhere along this period, in terms of changing the up-to-then parallel increasing trends in jack mackerel biomass as well as yearly catch levels. By contrast, from the mid-1990s onwards, the predominant trends at this fishery have been declining biomass levels together with also declining yearly aggregate catch levels.

A second important result from this paper refers to the estimated effects of the 'El Niño' phenomenon on the Chilean jack mackerel stock. The estimation results show, in a robust way, that an oceanic measure of 'El Niño' episodes not only has negative effects on contemporaneous jack mackerel biomass, but also negative biomass effects lasting for at least two more years. The latter is related to transmission over time of 'El Niño' effects through the biomass' age structure, given 'El Niño' effects on the rate of survival of eggs and larvae, a proportion of which will become –after a two year period– the new recruitment cohort at this fishery.

In order to enhance understanding about the relationship between fish biomass and catch yields in the fishery analysed, there is still a significant lack of scientific knowledge about the biology of jack mackerel stocks. Despite this limitation, and from the point of view of econometric analysis, an interesting new research area is related to improving understanding about spatial aspects affecting the relationship between fish abundance and catch yields. Related to the latter proposition, it is worth recalling that both Ricker (1958) and Gulland (1969) did already recommend, for purposes of 'stock assessment' methodologies, the stratification of catch and effort data by geographical areas. When the main objective is studying the relationship between fish biomass changes and catch yields, following their advice seems equally relevant.

Notes

1 Peña *et al*. (2003, 2004) replace the contemporaneous value of fish biomass by its one year lagged value, as a partial solution to contemporaneous correlation between the biomass variable and the residual term of the catch equation. Nonetheless, this strategy does not solve in a totally convincing way the issue of biomass endogeneity, as contemporaneous catch data is used to estimate current as well as past biomass values, when VPA stock assessment methodology is involved.

2 In the southeast Pacific coastal regions of South America, the arrival of an 'El Niño' phenomenon implies that warm and nutrient poor water from near the equator (north of Peru) now starts travelling southward along the coast. These changes in sea currents are related to shifts in the southeast trade wind system which itself is part of more complex trade wind patterns at the world level. Fagan (1999) provides an interesting description of the causes behind the 'El Niño' phenomenon.

3 There are two main competing hypotheses in this debate: a 'single stock' (Elisarov *et al*., 1993) versus a 'three stocks' theory. Serra (1991) supports the theory of three independent stocks (Chilean, Oceanic, and Peruvian).

4 Fishing operations did occur 210 to 250 miles off the Chilean coast. During the late 1980s, this fleet was composed of about 70 factory mid-water trawlers. In 1990 they caught about 1.1 million tons of jack mackerel in adjacent high seas waters in the southeast Pacific. Retreat from this fishery in 1992 was an economic consequence of the disintegration of the ex Soviet Union (Crone-Bilger, 1990, p. 118). During 2002-2005, renewed fishing operations by trawlers belonging to foreign fleets have been observed in these high seas areas. This includes fishing operations by Chinese, Korean and Russian fleets. According to Chinese Government's official statements, during 2002-2005 the Chinese fleet would have harvested between 76-120 thousand annual tons of jack mackerel (*El Mercurio*, 16/09/03 and 20/05/04). See also Peña-Torres *et al*. (2000). Chilean fishing companies have quoted an estimate of 250 thousand tons as the total jack mackerel catch obtained by foreign fleets in 2004 (*El Mercurio*, 22/03/05).

5 Considering the period 1985-97, i.e. before biological closures started to be used in the jack mackerel fishery, jack mackerel represented on average 88 per cent of total industrial landings in the central-southern region. The industrial catch of the three main harvested species fluctuated between 86 per cent and 98 per cent of total landings during 1985-2002.

6 Because of its emphasis on data sampling collection, the RFT Program imposed restrictions on the technical characteristics of participating vessels. Additionally, each of the latter had to carry on-board a technical observer. In practice, a dominant proportion of the participating vessels belonged to the 'large' (>800 m^3) vessel-size category. For example, during 1999 a total of 127 ships did participate at the RFT program for the jack mackerel fishery. Of that total, 70 belonged to the 'large' size category, 50 to the 'medium' size (301-800 m^3) group and only 7 to the 'small' (80-300 m^3) size category.

7 A fishery unit is composed of a particular fish species and a specific marine area.

8 Table 1 (columns 2 and 3) conceals the real (very fast) speed of the operational adjustments that were (immediately) triggered by the introduction, since February 2001, of individual catch quotas into this fishery. The reason for this is that during January 2001 the industrial fleet did operate under the so-called 'Olympic race' incentives. Hence, yearly statistics over-report the average monthly number of operating fishing vessels during the remaining of that year.

9 Regarding the fishery under analysis, estimations of the harvest technology which consider a more general (Translog) functional form can be found at Peña-Torres *et al*. (2004 and 2003).

[10] IFOP is a governmental institution whose mission is to provide scientific information as the basis for fisheries regulation and the preservation of marine resources.

[11] Catch is the dependent variable in the regressions. Therefore, its measurement error (given the use of per vessel landings) is captured by the error term of the regression. However, this measurement error does not affect the properties of the estimators.

[12] During the 1998-2000 period only a limited number of the purse seiners operating at the central-southern pelagic fishery was allowed to fish jack mackerel. A predominant proportion of the favoured vessels belonged to the large sized category. As a result, we observe a generalised fall in the share of jack mackerel landings, but with particular intensity in the vessel size categories below $800m^3$.

[13] In practice, a non trivial proportion of this industrial fleet's fishing trips are species specialised. This is related to the specific areas and fishing seasons in which vessels operate.

[14] For the period under analysis in this paper, jack mackerel annual biomasses have been estimated by IFOP on the basis of catch data sampling that was gathered by prospecting areas between 0-200 nautical miles from the coastline (from 33º up to 40º SL).

[15] During the 1998-2000 period, the RFT Program implied a *de facto* use of TACs, though only for jack mackerel; while the other pelagic species remained under closed entry but common property conditions.

[16] The sea surface temperature is measured at a region known as Niño 3.4 (120ºW-170ºW, 5ºNL-5ºSL), located in the East Central Equatorial Pacific region.

[17] Quoting from Chavez *et al*. (2003, p. 217), "The sardine and anchovy fluctuations are associated with large-scale changes in ocean temperatures; for 25 years, the Pacific is warmer than average (the warm, sardine regime) and then switches to cooler than average for the next 25 years (the cool, anchovy regime)."

[18] Hydro-acoustic biomass surveys, performed by IFOP during May-June of years 2003-2004, have found high concentrations of jack mackerel (especially of younger cohorts of the adult stock) in the 200-400 nm region of the total surveyed area (which also includes the 5-200 nm region, starting from 33º SL and covering up to 42º SL). A related hypothesis, which has been suggested as contributing explanation for the change in the spatial distribution of the Chilean jack mackerel stock, refers to inter-species competition effects triggered by a cyclical (in decadal scale) 'high-abundance' pulse of squid (*Dosidicus gigas*, also known as *Jibia*), a cephalopod which has been massively observed in the central-southern fishing grounds of Chile since 2002-2003.

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