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Sale price flexibilities of Mediterranean hake and red shrimp

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ABSTRACT

The formation of ex-vessel price of two important Mediterranean fisheries products (hake and red shrimp) was studied through an inverse demand approach, using data from the Catalonia bottom trawl fishery (NW Mediterranean). In both species, the landings by commercial category (proxy for fish size) and total landings determined the daily price fetched at the auction, as summarized by the quantity and scale coefficients ("flexibilities") derived from the inverse demand model. In general, quantity flexibilities were between −0.1 and − 0.6, indicating that a 1% increase in the landings of one category (for a given species) would reduce the average daily ex-vessel price by 0.1–0.6%. Scale flexibilities were generally lower than − 1, showing that these species tend to behave non-homothetically, especially for the large size categories. These results imply that changes to the quantities landed and the size composition of landings, resulting for instance from fisheries management measures, will affect sale prices. Simulations of sale price for scenarios of reduced landings, in line with fishing at maximum sustainable levels, showed that losses in revenue would be much less than the losses projected with constant prices. Similarly, higher landings resulting from rebuilt stocks would yield lower revenues from these stocks because of the generally negative flexibilities.

1. Introduction

Fish size is usually an important determinant of fish ex-vessel price in commercial fisheries, with larger individuals usually fetching higher unit price. The size structure of fisheries landings depends on the demographic structure of the fish population, as well as the selectivity pattern of the fishing gear. Hence, changes to the quantity or quality (sizes) of fish marketed will likely influence ex-vessel price [9,11]. Fisheries management may contribute unwillingly to changes to fish prices by limiting the quantity of catches (and landings) and the sizes that can be legally marketed. Fishers are usually "price-takers" because seafood is costly to store and its value quickly decreases with time [2]. Fishers cannot control the ex-vessel price and must accept (within certain limits) the price offered by the buyer. For this type of goods where quantity is fixed (on a given day or time period) and price is a function of quantity, the inverse demand model is usually applied [1–3].

In the Mediterranean Sea, chronic overfishing over the last decades has resulted in truncated fish populations, dominated by small sizes and young ages [4,14]. For instance, the catches of two important demersal species, such as hake (*Merluccius merluccius*) or red mullet (*Mullus surmuletus*), are dominated by age classes 0–2 [12]. The European Union reformed Common Fisheries Policy (EU Reg. 1380/2013) seeks to remedy this situation by adopting management plans that include inter alia a strong reduction of effort (for instance, up to 40% of historical levels in the Northwest Mediterranean Multi-Annual Plan, COM/2018/0115 final – 2018/050 (COD)), introducing more selective fishing gear or adopting fishing-exclusion zones. The correct implementation of this policy would lead in the short term to decreased catches, which would increase in the mid to long term (5–10 years), and, if minimum conservation reference sizes are effectively enforced, to important changes in the size structure of landings.

To examine the impact of fisheries conservation measures on ex-vessel prices I estimated empirical price equations for two important Mediterranean resources in the Catalonia bottom trawl fisheries (Northwest Mediterranean), hake (*M. merluccius*) and red shrimp (*Aristeus antennatus*), based on inverse demand models.

2. Material and methods

2.1. Data source

The daily fish sales by species and commercial category of each fishing vessel in Catalonia is recorded electronically at the fish auction of the 19 fishing ports in the area. I obtained the prices (€/kg) per species and commercial category for the six-year period 2014–2019 from the Fisheries Service of the Autonomous Government of Catalonia, who

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maintains the fish sales electronic data base. The bottom trawl fishery landed ~8000 t / year in the study period, for a value of ~60 million € / year. The two most important species (in value) of the bottom trawl fishery are hake (1000 t/year and 7.2 million €) and red shrimp (520 t/year and 18 million €). Hake is the target species of continental shelf bottom trawl fisheries in south Europe [5], including the Mediterranean Sea, and the red shrimp is the most important deep water (>500 m depth) resource in the western Mediterranean [8]. The prices were deflated to constant 2014 prices based on the harmonized index of consumer prices for Spain provided by [13], Appendix p. 21). A summary of relevant quantities in the data set is shown in Table 1. The price of hake varied from 7.65 to 10.22 €/kg for the smallest and largest categories, while for red shrimp the prices ranged from 31.79 for the lowest grade to 42.66 €/kg for the best grade. The big difference between hake and red shrimp prices already shows that hake is consumed as an ordinary table fish while red shrimp is more often consumed as a luxury item during special holidays or at seaside restaurants. The share (w_i) of the four commercial categories indicates that hake landings correspond basically to juvenile individuals (78.3% of landings are in categories 3 and 4, that is < 30 cm TL). In red shrimp the four commercial categories are more equally represented, but the two largest grades make up more than half of the landings (56.5%).

The ex-vessel price of both species fluctuated without trend along the study period (Fig. 1A, B). Seasonality can be observed in both series, with higher unit price corresponding to summer and winter in most years for hake and increase in prices around Christmas time for red shrimp. The smaller size categories (3 and 4) dominated the landings of hake (Fig. 1C; Table 1). The largest share of landings of red shrimp were made of categories 2 and 4, with category 1 becoming more important in the last two years of the series (Fig. 1D; Table 1).

2.2. Statistical estimation

I applied the empirical estimation method of Brown et al. [3] and Sjoberg [11] to derive the flexibilities (corresponding to elasticities in regular demand models) of prices for the four size categories in which the species are marketed at first sale, by way of estimating *quantity* (e_{ij}) and *scale* (e_i) effects of inverse demand models. The quantity effect corresponds to the change in price of fish in category *i* (p_i) with a change in the quantity landed in category *j* (q_j). The scale effect is the change in the price of size *i* due to a change of the total quantity landed Q (all sizes combined). Following Brown et al. [3] and Sjoberg [11], a general

Table 1
Summary data for the main two stocks captured by the Catalonia bottom trawl fishery (NW Mediterranean), as average values for the period 2014–2019. The products are auctioned according to four commercial categories, or grades, with the approximate weight shown. Weights were transformed into sizes with the parameters used for stock assessments [12].

		Category 1 “extra”	Category 2 large	Category 3 medium	Category 4 small
Hake (Merluccius merluccius)	price (€/kg)	10.22	9.56	8.01	7.65
	share (w_i)	11.6%	10.1%	30.5%	47.8%
	weight (g)	>400	200–400	100–200	<100
	size (cm TL)	>38	30–38	25–30	<25
red shrimp (*Aristeus antennatus*)	price (€/kg)	42.66	41.99	40.86	31.79
	share (w_i)	21.7%	34.8%	16.2%	27.3%
	weight (g)	>30	20–30	15–20	<15
	size (mm CL)	>46	39–46	34–38	<34

inverse demand model for fish prices can be given by (time subindex implicit):

$$w_i d(\log \pi_i) = \sum_{j=1}^{n} \left(e_{ij} - \theta_2 w_i \left(\delta_{ij} - w_j\right)\right) d\left(\log q_j\right) + \left(e_i - \theta_1 w_i\right) d(\log Q) \quad (1)$$

where *d* is a difference operator, $w_i = (p_i\, q_i) / m$ is the share of the total value of category *i*, $m = \sum_i p_i q_i$ is the total value, $\pi_i = p_i / m$, δ_{ij} is a Kronecker delta, and $log\, \pi_i$ is the Divisia quantity $\log \pi_i = \sum_i w_i \log p_i$. Likewise, $loq\, Q$ is the corresponding Divisia quantity: $\log Q = \sum_i w_i \log q_i$. Depending on the values of the parameters θ_1, $\theta_2 \subset [0,1]$ this general model can be transformed into one of the models usually considered in the inverse demand literature (Table 2).

To help interpretation of the model, the quantity and scale effects were transformed into quantity and scale flexibilities f_{ij} and ϕ_i. Quantity flexibilities can be interpreted as the percentage change in fish price of category *i* from 1% change in landings of fish in category *j*. Scale flexibility corresponds to the percentage change of fish price of category *i* when total landings increase by 1%. The transformation from model effects into flexibilities is obtained by the following equations:

$$f_{ij} = \frac{e_{ij}}{w_i} - \theta_2 \left(\delta_{ij} - w_j\right) + w_j \phi_i \quad (6)$$

$$\phi_i = \frac{e_i}{w_i} - \theta_1 \quad (7)$$

It is difficult to select from the models in Table 2 on purely theoretical grounds. Following the empirical approach of Sjoberg [11], I estimated the general model in Eq. (1) for each species with the constraints of homogeneity $\sum_i e_{ij} = \sum_j e_{ij} = 0$ and symmetry $e_{ij} = e_{ji}$. Then I estimated the models in eqs. 2–5 and used a log-likelihood ratio test to examine which model(s) cannot be rejected as nested in the general model. The parameters of the equations in each model were estimated with the technique of Seemingly Unrelated Regression [16,17] in STATA 15 (procedure *sureg*, [15]).

3. Results and discussion

For both species, the model that could not be rejected as nested in the general model was the RIDS model (Table 3).

The quantity and scale flexibilities for the selected model for hake are given in Table 4. The scale flexibilities for category 2 and 4 were − 1.235 and − 1.165, suggesting that large hake and small hake behave non-homothetically, as a luxury product in this market (category 1 was statistically not different from −1, indicating homothetic preference). Conversely, for category 3 the scale flexibility was larger than − 1, suggesting that medium hake behaves as a “necessity” in this market. The quantity flexibilities for their own category were not significantly different from 0 for categories 1 and 2, and they were relatively low for categories 3 and 4 (−0.162 and −0.304, respectively). The cross-quantity flexibilities showed relatively high negative values for categories 3 and 4, showing that an increase in the quantity of the immediately superior or inferior hake grade affected negatively the price fetched. Instead the quantity flexibilities if categories 3 and 4 on the price of categories 1 and 2 were low.

In the case of red shrimp, scale flexibilities are lower than − 1 (as could be expected from the "luxury" status of this product) for categories 2 ("large"), 3 ("medium") and 4 ("small"). For category 1 ("extra large") however, a positive value (e1 = 0.278) is estimated. This value is difficult to explain without knowing the details of this specific market, but it suggests a reinforcement mechanism whereby 1% more product on the market leads to a 0.278% price increase for category 1. A relatively high and positive quantity flexibility is also observed for the quantity of category 1 on the price of category 4 (e_{14} = 0.464). The quantity flexibilities for their own category were negative with values around − 0.3, except for category 3 which is practically 0 (e_{33} =

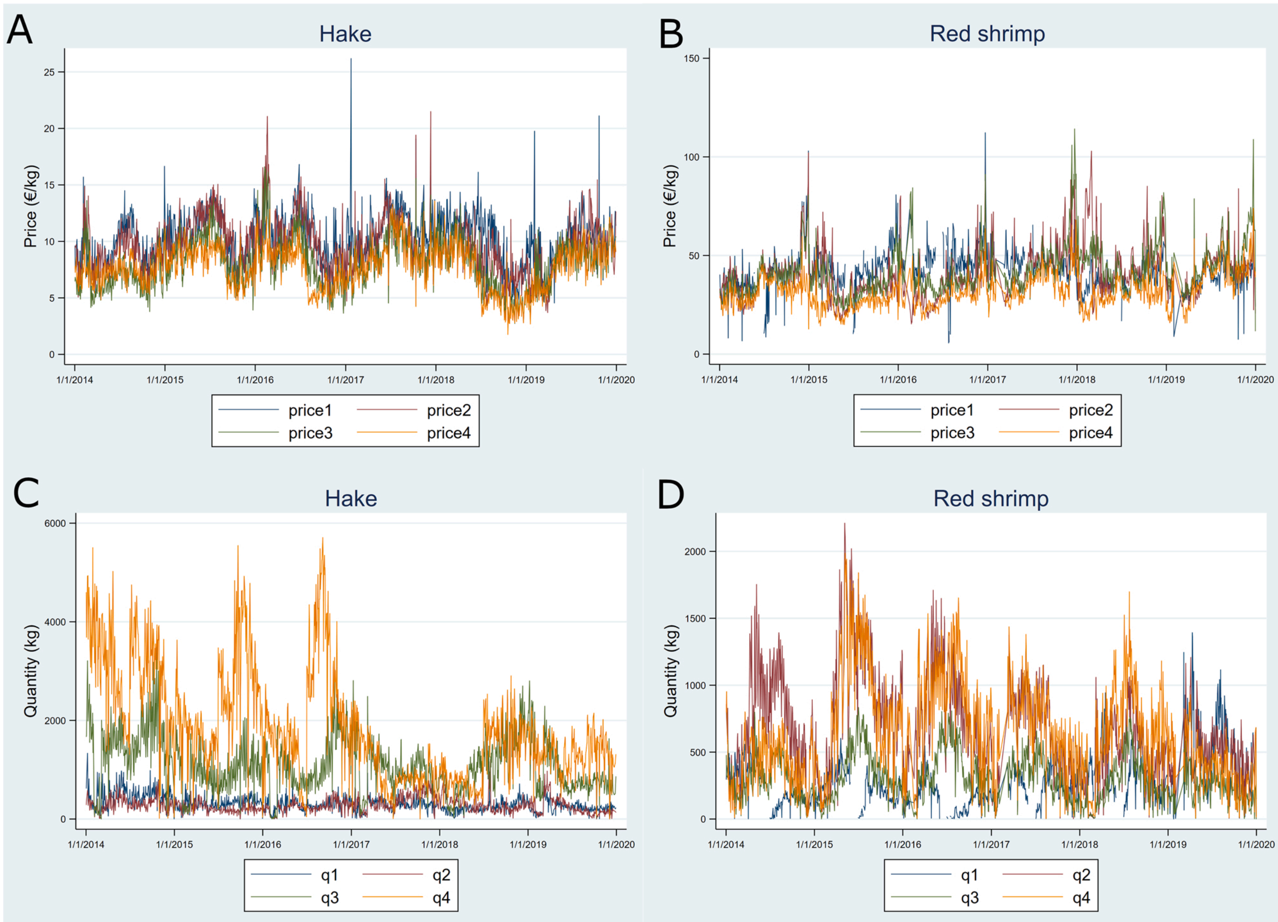

Fig. 1. Top row: Evolution of prices (€/kg) of hake (A) and red shrimp (B) for the four commercial categories. Bottom row: evolution of landings (kg/day) of hake (C) and red shrimp (D) by commercial category. Prices are deflated to 2014 constant values.

Table 2
Specific inverse demand models obtained by varying parameters $\theta_1, \theta_2 \subset [0,1]$ of Eq. (1).

Coefficients	Model	Source
$\theta_1 = \theta_2 = 1$ $e_i = \beta_i$ $e_{ij} = \eta_{ij}$	$d(w_i) = \sum_j \eta_{ij} d(\log q_j) + \beta_i d(\log Q)$ (2)	AIIDS[3]
$\theta_1 = 1;\ \theta_2 = 0$ $e_i = \beta_i$ $e_{ij} = \gamma_{ij}$	$w_i d(\log \frac{p_i}{P}) = \sum_j \gamma_{ij} d(\log q_j) + \beta_i d(\log Q)$, (3) where P is the Divisia price	DICBS[2,7]
$\theta_1 = \theta_2 = 0$ $e_i = \alpha_i$ $e_{ij} = \gamma_{ij}$	$w_i d(\log \pi_i) = \sum_j \gamma_{ij} d(\log q_j) + \alpha_i d(\log Q)$(4)	RIDS[3]
$\theta_1 = 0;\ \theta_2 = 1$ $e_i = \alpha_i$ $e_{ij} = \eta_{ij}$	$d(w_i) - w_i d(\log Q) = \sum_j \eta_{ij} d(\log q_j) + \alpha_i d(\log Q)$ (5)	DINBR[3]

−0.083). The cross quantity flexibilities varied from practically 0 for e_{41} to the relatively high $e_{24} = -0.473$.

In addition to the intrinsic interest of estimating the flexibilities for two different seafood products of Mediterranean trawl fisheries, these results have an important applied aspect in that they allow to forecast the prices of these species when the quantity or quality of landings change due, for instance, to the implementation of fisheries conservation measures. Specifically, for these highly overexploited species the recommendation from stock assessment results is to decrease fishing effort to obtain the maximum sustainable yield. According to STECF [12], fishing at MSY would imply a reduction of catches of hake of 77% ([12], p. 37) and 67% for red shrimp ([12], p. 146) in the short term.

Table 3
Log likelihoods and ratio test for the inverse demand models tested. The log likelihood ratio test is based on 2 * (Log likelihood general model – loglikelihood restricted model) ~ χ2 with degrees of freedom corresponding to the difference between the two models being tested.

	Log likelihood and d.f.	Log likelihood ratio test
hake		
General model	11,553.4, 16	
Model in Table 1:		
AIIDS (Eq. 2)	11,509.2, 18	$p < 0.001$
DICBS (Eq. 3)	11,513.1, 18	$p < 0.001$
RIDS (Eq. 4)	11,550.8, 18	$p = 0.074$
DINBR (Eq. 5)	11,548.3, 18	$p = 0.006$
red shrimp		
General model	6678.7, 16	
Model in Table 1:		
AIIDS (Eq. 2)	6601.8, 18	$p < 0.001$
DICBS (Eq. 3)	6642.6, 18	$p < 0.001$
RIDS (Eq. 4)	6676.3, 18	$p = 0.091$
DINBR (Eq. 5)	6668.8, 18	$p < 0.001$

Assuming that the decrease in landings is proportional across all commercial categories (i.e. following the same proportions, or shares w_i, shown in Table 1), prices per category would increase substantially and the new value of landings would decrease by 31.94% and 28.47% for hake and red shrimp, respectively (Tables 6 and 7). If the overall reduction in catches were accompanied by a relatively more important decrease in the catches of the smaller size categories and an increase in the larger categories, the value of landings would also decrease (for hake

Table 4
Point estimates with 95% CI of quantity and scale flexibilities for the inverse demand RIDS model applied to the price and quantity data set for hake.

	Quantity flexibilities (e_{ij})				Scale flexibilities (ei)
	category 1	category 2	category 3	category 4	
category 1	-0.010 (−0.068, 0.048)	-0.024 (−0.077, 0.029)	-0.470 (−0.570, −0.371	-0.654 (−0.804, −0.505)	-0.962 (−1.123, −0.801)
category 2	-0.204 (−0.270, −0.138)	-0.007 (−0.067, 0.054)	-0.408 (−0.522, −0.295)	-0.694 (−0.864, −0.524)	-1.235 (−1.419, −1.052)
category 3	-0.165 (−0.197, −0.132)	-0.125 (−0.155, −0.096)	-0.162 (−0.218, −0.106)	-0.531 (−0.615, −0.447)	-0.654 (−0.745, −0.564)
category 4	-0.120 (−0.143, −0.096)	-0.151 (−0.172, −0.129)	-0.327 (−0.367, −0.286)	-0.304 (−0.364, −0.243)	-1.165 (−1.230, −1.099)

Table 5
Point estimates with 95% CI of quantity and scale flexibilities for the inverse demand RIDS model applied to the price and quantity data set for red shrimp.

	Quantity flexibilities (e_{ij})				Scale flexibilities (ei)
	category 1	category 2	category 3	category 4	
category 1	-0.303 (−0.379, −0.226)	-0.316 (−0.402, −0.229)	-0.412 (−0.487, −0.337)	0.464 (0.372, 0.557)	0.278 (0.171, 0.384)
category 2	-0.384 (−0.424, −0.345)	-0.239 (−0.285, −0.194)	-0.042 (−0.081, −0.003)	-0.473 (−0.522, −0.425)	-1.406 (−1.461, −1.350)
category 3	-0.197 (−0.239, −0.154)	-0.352 (−0.400, −0.303)	-0.083 (−0.125, −0.041)	-0.354 (−0.405, −0.302)	-1.380 (−1.440, −1.321)
category 4	-0.073 (−0.120, −0.025)	-0.526 (−0.580, −0.472)	0.013 (−0.034, 0.0596)	-0.376 (−0.434, −0.319)	-1.195 (−1.261, −1.128)

Table 6
Short-term forecast landings of hake under Fmsy ([12], Scenarios 1 and 2) and hypothetical increase in 20% of landings from 2019 (Scenarios 3 and 4). Values estimated from the coefficients in Table 4 compared to a naïve estimate of value assuming the average price for hake in 2019 (8.61 €/kg). Scenarios 2 and 4 assume a relative decrease in the catch composition of 10% for category 4, and increase of 50% for each of categories 3, 2, 1.

	Landings (t)	Value (M €)	variation from 2019 (value)
Current (2019)	663.92	5.42 (naïve: 5.72)	–
Scenario 1 - 77% landings across all size categories	152.70	3.69 (naïve: 1.31)	- 31.94%
Scenario 2 -77% landings with lower catches in categories 3–4	152.70	3.43 (naïve: 1.31)	- 36.61%
Scenario 3 + 20% landings across all size categories	796.70	5.97 (naïve: 6.86)	+ 10.17%
Scenario 4 + 20% landings with lower catches in categories 3–4	796.70	1.50 (naïve 6.86)	- 72.23%

by 36.61% and for red shrimp by 26.68%, Tables 6 and 7). That is, the decrease in landings value (around 30%) would be disproportionally lower than the decrease in landings volume (77% and 67%). Conversely, rebuilt fish stocks that permit a future increase in landings of 20% (for instance) would not correspond to a proportional increase in revenues but only 10.17% for hake and 11.87% for red shrimp (Tables 6 and 7), keeping the original value shares. If this 20% increase in landings was

Table 7
Short-term forecast landings of red shrimp under Fmsy ([12], Scenarios 1 and 2) and hypothetical increase in 20% of landings from 2019 (Scenarios 3 and 4). Values estimated from the coefficients in Table 5 compared to a naïve estimate of value assuming the average price for red shrimp in 2019 (40.51 €/kg). Scenarios 2 and 4 assume a relative decrease in the catch composition of 40% for category 4, and increase of 20%, 37% and 48% for categories 3, 2, 1 respectively.

	Landings (t)	Value (M €)	variation from 2019 (value)
Current (2019)	366.43	15.15 (naïve: 14.84)	
Scenario 1 - 67% landings across all size categories	120.92	10.84 (naïve: 4.85)	- 28.47%
Scenario 2 -67% landings with lower catches in category 4	120.92	11.11 (naïve: 4.85)	- 26.68%
Scenario 3 + 20% landings across all size categories	439.17	16.95 (naïve: 17.81)	+ 11.87%
Scenario 4 + 20% landings with lower catches in category 4	439.17	13.46 (naïve: 17.81)	- 11.14%

obtained from a more selective fishery, with relatively lower catches of the smaller categories, a large decrease of 72.23% of value for hake and a moderate decrease of 11.14% for red shrimp could be anticipated (Tables 6 and 7). Although it is difficult to convert directly from commercial categories into size frequencies, the implementation of a hypothetical selective net that would reduce the catches of immature hake or red shrimp simulated in Scenarios 2 and 4 of Tables 6 and 7 shows that both lower and higher landings than at present could affect the value of the landings due to changes in fish prices.

In summary, taking into account the price flexibilities we see that strong short-term reduction in catches may not represent a proportional reduction in fisheries revenue, while increases in landings may even yield less revenues, due to the generally negative flexibilities that fisheries landings obtain [11]. These results should also be taken into account in the application of bioeconomic models for management advice, where prices are usually assumed constant [6,8,10], independently of size or quantities landed, and may yield excessively negative economic short term forecasts and excessively optimistic mid to long term forecasts.

CRediT authorship contribution statement

Francesc Maynou: Conceptualization, Methodology, Writing.

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