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RESEARCH ARTICLE

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Balancing environmental concerns and efficiency in Mediterranean fisheries: Economics of production with a look at market trends

Alberto Ceccacci*, Luca Mulazzani and Giulio Malorgio

Department of Agricultural and Food Sciences, University of Bologna, Viale Fanin 50, 40127, Bologna, Italy

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Abstract – The fishing sector in the Adriatic Sea is exposed to stricter regulations due to the negative ecological impact of large-scale fisheries, while increasing socio-economic challenges threaten the profitability of the industry. We apply Stochastic frontier and Price formation analysis to the *rapido* fishery of Chioggia (Italy) in order to investigate potential strategies to enhance the economic performance of the fishery, considering both effort restrictions and market trends. The use of two different methodological approaches emphasizes the need for a comprehensive and flexible approach to fisheries management, taking into account seasonal fluctuations in efficiency and average prices. The results reveal that efficiency variations are significantly influenced by seasonal factors and stock availability, thus indicating a limited capacity of fishers to adapt to changing market conditions. We emphasize the importance of flexible scheduling of fishing days and discuss the opportunity for implementing mixed management systems incorporating a Total Allowable Catch or quotas.

Keywords: Beam trawling / fisheries economics / fish market / stochastic frontier analysis / efficiency

1 Introduction

In order to strengthen the sustainability and resilience of European fisheries, the European Commission has recently recalled the importance of reducing the impact of fishing activities on the seabed. This implies that Member States are expected to adopt measures prohibiting mobile bottom fishing in the marine protected areas (MPAs) that are Natura 2000 sites and ensure that by 2030 mobile bottom fishing is phased out in all MPAs (European Commission, 2023a). Being one of the most impacting fisheries in terms of carbon footprint (Sala et al., 2022), seabed damages (Armelloni et al., 2021) and unwanted catches (Pranovi et al., 2001), the Italian *rapido* fishery in the Central/Northern Adriatic Sea (GSA17) has been indeed subject to increasing effort limitations in recent years (8663 days in 2020, 7443 in 2023). The reduction in fishing effort is expected to generate a decrease in landings which, in turn, should positively affect the price of the most relevant target species, thus addressing the need to maintain prices at appropriate levels by channeling production in order to take advantage of market opportunities (European Commission, 2023a). However, as stressed by NISEA (2022a), the poor performance of several segments of the Italian fleet (including *rapido*) is indeed related to the fact that first sale prices of most species are not keeping up with inflation (Fig. 1).

Being aware that the *rapido* fishery represents a compelling case study due to the substantial environmental issues it is associated with, our focus lies on 31 *rapido* boats (a type of beam trawl) from Chioggia port (Veneto region), which represent approximately 86.1% of the *rapido* fleet in the region and account for 34.1% at the national level (NISEA, 2022b). This fishery- as many others in the Mediterranean Sea (Carpi et al., 2017)- is regulated through inputs control, meaning that management measures aim at reducing pressure on target species by fishing effort reductions. The multiannual management plan in force in the area, aimed at ensuring the sustainability of key demersal fish stocks in the Adriatic Sea, holds particular significance for the long-standing *rapido* trawl fishery operating in the western side of the north-central Adriatic. This fishery, utilizing specialized gear to target flatfish and sediment-dwelling species, has raised environmental concerns due to its invasive nature, impacting macro and meiobenthic communities and indirectly interfering with the distribution of prey species essential for fish stocks (Armelloni et al., 2021). For this reason, the establishment of

*Corresponding author: alberto.ceccacci2@unibo.it

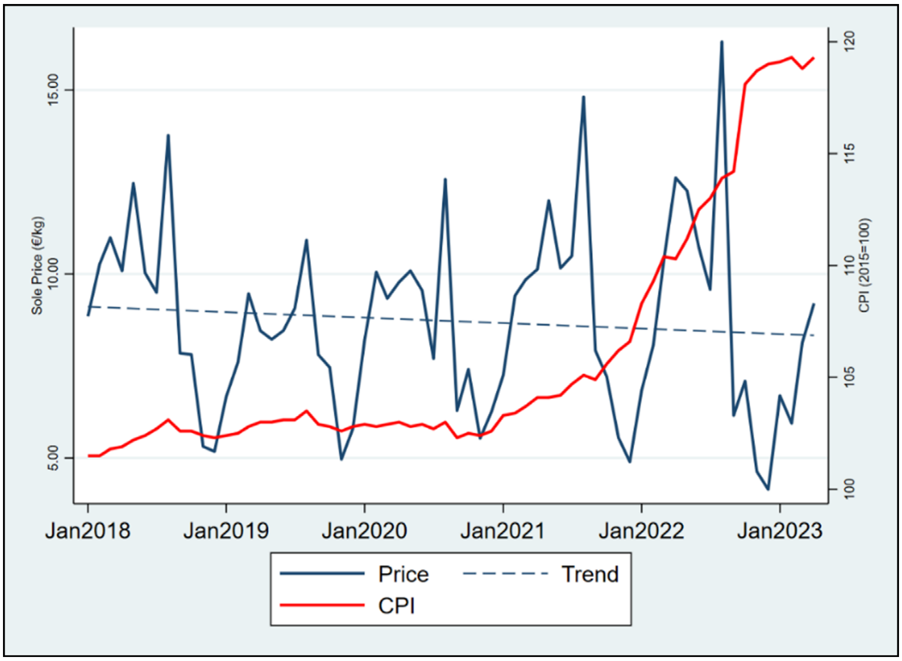

Fig. 1. First sale price of sole at Chioggia Market and Italian consumer price index (CPI). Source: EUMOFA, ISTAT.

Fig. 2. Quantity and price series of sole sold at Chioggia Fish Market in 2019.

a 5 yr (2022–2026) fishing effort regime for bottom otter trawls and *rapido* trawls underscores the commitment to sustainable fisheries management, with effort quotas determined annually based on scientific advice (Recommendation GFCM/43/2019/5).

Fisheries management relying on input controls assumes that all vessels within a fleet have similar levels of efficiency, meaning that limitations in fishing effort are expected to lead to proportionate reductions in fishing mortality. However, if variations in technical efficiency are observed, the effectiveness of management based on using input controls may be impacted (Pascoe and Tingley, 2007). This implies that, in the presence of heterogeneity, a flexible and versatile management framework that takes into account local characteristics (such as specific areas, time periods, and fishers' behaviour) as well as market trends of relevant species (Fig. 2) could provide a positive supplement to current regulations, which mainly focus on fishing days reduction, a biological ban in the Summer season (approximately six weeks between late July and early September) and other technical measures (MASAF, 2023). In this work we expand previous research on the *rapido* fishery (Pranovi et al., 2015; Russo et al., 2020) by conducting a comprehensive examination that integrates the study of technical efficiency with the assessment of the economic performance of vessels and price formation analysis, supporting potential reforms in current management practices.

In the realm of fisheries economics, the evaluation of technical efficiency has emerged as a pivotal tool for assessing the performance and sustainability of fishing operations (Coglan and Pascoe, 2007; Yang et al., 2017; Kiyama and Yamazaki, 2018; Sangün et al., 2018; Gómez and Maynou, 2020; Dağtekin et al., 2021). Nevertheless, several approaches can be found in the literature with regard to the choice of the relevant inputs and outputs on which efficiency measurement should be based. While input variables selection is not our objective, in this study we delve into the intriguing dimension of comparing technical efficiency scores when output is measured in terms of weight versus the value of landings. This choice is not merely an academic exercise; rather, it reflects the complex interplay of market dynamics, risk aversion, and decision-making strategies within the fishing industry. By assessing the performance of vessels on the basis of both a physical and monetary measure, our study aims to investigate the economic and behavioural underpinnings that drive fishing operations, ultimately shedding light on the adaptability of vessels in the face of changing market conditions and ecological challenges. The intuition behind this study builds on previous research by Herrero and Pascoe (2003), who applied Stochastic Frontier Analysis (SFA) to study the efficiency of the Spanish South-Atlantic trawl fishery using both revenue and landings weight as dependent variables. Their findings suggest that fishers use a spectrum of strategies, and only a minority are primarily concerned with maximizing catch weight. These strategy differences may be indicative of varying risk preferences, with the more risk-averse fishermen opting for a trade-off that ensures a more predictable catch quantity at the expense of potential value. We expand this type of efficiency analysis by incorporating an investigation of seasonality effects and the relationship between prices and quantities of primary species in the fishery in order to offer insights for maintaining price levels at an optimal range and capitalizing on market opportunities.

The research questions behind our study are therefore the following. First, are there any differences in terms of efficiency among *rapido* vessels depending on the output variable used (landings weight or value)? Second, considering both the efficiency of vessels and market trends of target species, which management approaches can be proposed to improve the economic profitability of the fishery while ensuring the sustainable use of marine resources? It is important to emphasize that while this analysis primarily concentrates on enhancing short-term efficiency, it is essential for future management interventions to be in harmony with the fishery's long-term sustainability goals. These sustainability objectives encompass biological considerations, which, though not covered in this article, are integral to a comprehensive fisheries management approach.

2 Methodology

Technical efficiency can be defined as the ability of an agent to maximize the output given a set of inputs (output orientation) or minimize the use of inputs required to produce a given output (input orientation), with the former formulation being the most used in fisheries (Pascoe and Tingley, 2007). Considering the stochastic nature of the production process at sea, we apply SFA due to its ability to account for statistical noise through the incorporation of random errors (Herrero and Pascoe, 2003). Following Battese and Coelli (1995), we apply the stochastic frontier production function

$$y_{\mathrm{it}} = f(x_{\mathrm{it}}; \alpha) + v_{\mathrm{it}} - u_{\mathrm{it}}, \tag{1}$$

where y_{it} denotes the vessel output per trip (landings in weight and value), x_{it} are the inputs to production (fishing time and engine power of the vessel), v_{it} denotes stochastic noise and u_{it} represents technical inefficiency. The random errors are assumed to be i.i.d. following a normal distribution $N\left(0, \sigma_v^2\right)$, while several distributional assumptions exist regarding the inefficiency component. A common approach in the fisheries literature is to model it as a function of exogenous variables (Pascoe and Coglan, 2002). The inefficiency determinants function follows the form $u_{it} = \delta_0 + z_{it}\delta + w_{it}$ where z_{it} is a vector of vessel-specific characteristics affecting efficiency, δ is a vector of parameters, and w_{it} is the i.i.d. error term. Estimates of technical efficiency per trip by each vessel are given by

$$TE_{it} = e^{-u_{it}} = e^{-(\delta_0 + z_{it}\delta + w_{it})}, \tag{2}$$

describing the ratio of the actual output over the maximum that could be obtained given the inputs employed (Battese and Coelli, 1995; Fousekis and Klonaris, 2003). The parameters of the stochastic frontier and the model for inefficiency effects are estimated simultaneously using the maximum likelihood method. In addition, to estimate the fishing technology's relationship between inputs and output, a functional form must be selected. A common option is represented by the Cobb-Douglas production function, which is a special case of the more general Translog function. The latter is usually considered as the most flexible form (Van Nguyen et al., 2019) because it enables elasticities of substitution to vary, while the Cobb-Douglas maintains a constant elasticity of production across all inputs and the elasticity of substitution is fixed at 1, meaning that the degree of substitutability among inputs remains constant (Squires and Kirkley, 1999). Key tests to be conducted hence include the choice of the functional form (Cobb-Douglas vs Translog), the existence of a frontier and the distribution of inefficiency (Pascoe et al., 2003).

Concerning market dynamics of relevant species, we investigate the role of *i*) sold quantities, *ii*) day of the week and *iii*) seasonality in influencing the price of fish combining the inverse demand modelling and hedonic pricing approach. The hedonic pricing approach posits that products are comprised of various traits and are esteemed for their utility-inducing features. The market value therefore mirrors the amalgamation of these attributes, which, notably lack a direct price. Consequently, it becomes viable to assess the worth of these constituent attributes by scrutinizing systematic price fluctuations (Rosen, 1974), making the hedonic price method a valuable tool for assessing price premiums associated with quality attributes in the agri-food market (Costanigro et al., 2011). On the one hand, demand models in fisheries generally assume that the supply of fish is exogenously determined due to the influence of external factors not under fishers' control (weather and water conditions, biological shocks) and because fish is a perishable item that needs to be sold quickly (Nielsen, 2000; Asche and Hannesson, 2002; Jaffry et al., 2005). On the other, hedonic models- specifying the price of fish as a function of its attributes- are also frequently applied in fisheries economics in order to examine the value of quality attributes such as size, freshness, origin and fishing gear (Kristofersson and Rickertsen, 2004; Asche and Guillen, 2012; Krigbaum and Anderson, 2021). Combining the two approaches following Guillen and Maynou (2015), the model is written in its general form as

$$P_{\mathrm{it}} = f(a_1, \ldots, a_n), \tag{3}$$

where the price of fish i at time t is a function of vector $A = (a_1, \ldots, a_n)$ including the variables of interest, mainly quantities and temporal patterns. The function permits an evaluation of the significance of each attribute while keeping all other attributes constant. Attribute a can be measured either on a continuous scale or by using a dummy variable, depending on its nature (Roheim et al., 2011).

3 Data description and econometric model

The dataset contains information on 2,404 trips by 31 vessels during 2019 Table 1 and it was built from AIS data provided by the Italian Coast Guard, which have been matched with the EU Fleet Register to retrieve information on the characteristics of vessels. Data on landings and daily prices for the most relevant species (sole, cuttlefish, purple dye murex, caramote prawn, spottail mantis shrimp, queen scallop and great Mediterranean scallop)- covering approximately 80% of the total landed value by the fleet in the basin (STECF, 2022)- are used to compute trip revenues. Detailed information on the procedure to build the dataset can be found in Russo et al. (2020).

With regard to the study of technical efficiency, the estimated equations are given by

$$\begin{aligned} \ln LF_{it} = {} & \alpha_0 + \alpha_T \ln T_{it} + \alpha_{KW} \ln kW_i + \alpha_{TT}(\ln T_{it})^2 \\ & + \alpha_{KWKW}(\ln kW_i)^2 + \alpha_{TKW}(\ln T_{it} \cdot \ln kW_i) \\ & + \alpha_4 D_t + v_{it} - u_{it}, \end{aligned} \tag{4}$$

where LF_{it} are the landings of fish, measured firstly in weight (kg) and secondly in value (€), T_{it} is fishing time, kW_i denotes power and D_t is a monthly dummy describing stock fluctuations. These input variables capture the contribution of fishing effort and stock availability to production (Andersen, 2002). Technical efficiency effects are then defined by

$$u_{it} = \delta_0 + \delta_Y A_i + \delta_L LC_i + w_{it}, \tag{5}$$

where A is the boat age and LC is the length class. Age is assumed to be an exogenous factor negatively affecting efficiency (Van Nguyen et al., 2019), while the length class is an additional criterion for fishing opportunities allocation according to national regulations (MASAF, 2023), based on the definition of effort groups as a combination of gear type and vessel length class ("fleet segment") (Recommendation GFCM/43/2019/5).

Concerning the analysis of fish prices at Chioggia Market[1], the model is presented in a double log form in order to facilitate the interpretation of the quantity coefficient as elasticity (Carrol et al., 2001). The model to be estimated is therefore specified as

$$\ln P_{it} = \beta_0 + \beta_1 \ln Q_{it} + \beta_2 DW_t + \beta_3 M_t + \beta_4 YC_t + \epsilon_{it}, \tag{6}$$

where the price of fish i at time t is a function of the quantity sold at the market Q, the day of the week DW, the month M and the year YC. The constant term β_0 indicates the price for the base category while ε_{it} is a normally distributed random error term. First, the Augmented Dickey-Fuller test indicates that null hypothesis of non-stationarity can be rejected for all seven time series of fish prices. Then, having detected hetero-skedasticity and autocorrelation based on the White's and Breusch-Godfrey LM tests, the parameters of equation (6) are estimated by OLS using Newey–West standard errors with one weekday lag (Newey and West, 1987; Greene, 2003). Lastly, checking for multicollinearity, the Variance Inflation Factors test (Chatterjee and Hadi, 2006) indicates that the selected variables can be included together in the model (Tab. S1).

4 Results

First, it is important to provide a general overview of seasonality effects concerning landings and prices of the seven species under consideration. From Table 2 we can observe that in *rapido* fishery of Chioggia in the year 2019, sole is by far the most relevant species in terms of weight (432,685 kg), followed by queen scallop (219,352 kg) and cuttlefish (169,736 kg), while great Mediterranean scallop (89,081 kg), murex (51,581 kg), caramote prawn (42,721 kg) and mantis shrimp (13,018 kg) play a secondary role. Nevertheless, taking into account average monthly prices, it emerges that the contribution of each species to the total value of landings may not correspond to its importance measured in weight terms. For instance, queen scallop represents 22% of landings, but its low average price (fluctuating between 3.80 €/kg in September and 5.83 €/kg in March) implies that its contribution to total value decreases to 13% of the total. On the other hand, despite its remarkable fluctuations in price (from 7.43 €/kg in November to 16.93 €/kg in July), cuttlefish landings basically have the same relevance in terms of contribution to both weight and value (around 17% of the total).

Before providing for efficiency estimates, we show the magnitude and statistical significance of the parameters of the production function and inefficiency effects (Tab. 3) and conduct some tests concerning the structural form of both the weight and value models. First, it should be noted that the parameter lambda- which indicates the ratio of the standard deviation of the inefficiency term σ_u to the standard deviation of the stochastic term σ_v- is statistically significant and different from zero (p-value < 0.01), highlighting the greater importance of technical inefficiency as opposed to random

[1] Daily fish prices for the years 2019 and 2020 have been provided by representatives of Chioggia Fish Market.

Table 1. Summary statistics per fishing trip (year 2019).

Variable	25° Percentile	Median	75° Percentile	Mean	Std.Dev.
Engine power (kW)	338.00	441.00	515.00	433.17	121.00
Length (meters)	21.70	23.00	24.37	22.87	2.47
Age (years)	25.00	29.00	35.00	31.47	9.96
Fishing time (hours)	12.11	17.55	27.64	19.48	10.36
Fuel (liters)	717.52	1179.84	2095.38	1458.38	963.50
Landings weight (kg)	210.63	341.98	552.75	423.53	357.97
Landings value (€)	1675.13	2718.22	4292.69	3273.53	2721.71

Rapido vessels analysed = 31; N = 2404 observations.

Table 2. Monthly variations in landings and prices in Chioggia (year 2019).

Month	Sole		Cuttlefish		Murex		Caramote prawn		Mantis shrimp		Queen scallop		Great Med. scallop	
	Landings (kg)	Price (€/kg)	Landings (kg)	Price (€/kg)	Landings (kg)	Price (€/kg)	Landings (kg)	Price (€/kg)	Landings (kg)	Price (€/kg)	Landings (kg)	Price (€/kg)	Landings (kg)	Price (€/kg)
Jan	54,698	8.25	47,756	7.66	2,022	3.46	4,454	14.57	3,634	6.39	18,085	4.65	8,177	9.71
Feb	43,264	9.25	35,482	8.12	991	3.38	3,604	15.06	3,590	8.48	21,244	4.20	8,206	10.70
Mar	29,615	10.18	18,984	8.61	2,792	3.25	3,431	19.08	1,264	9.57	16,139	5.83	9,257	9.26
Apr	37,677	9.76	10,243	7.94	5,490	2.96	4,662	21.99	849	7.97	30,893	5.43	11,287	8.65
May	35,584	9.66	1,993	8.67	6,553	2.88	3,179	21.83	163	7.81	29,420	5.14	10,515	8.93
Jun	25,940	9.37	458	11.18	5,431	3.23	1,770	19.98	35	7.47	26,543	4.55	10,088	8.02
Jul	23,096	9.22	212	16.93	3,245	3.17	1,259	20.60	128	5.84	21,966	4.36	7,331	10.10
Sep	30,313	8.97	4,285	9.04	4,326	3.19	4,055	18.22	416	5.67	12,473	3.80	6,056	11.28
Oct	43,798	9.15	11,906	8.26	6,668	2.90	3,392	16.45	819	6.57	15,686	3.95	8,372	10.56
Nov	53,670	6.98	16,168	7.43	6,118	2.30	7,838	15.50	595	5.43	11,408	4.00	4,317	11.97
Dec	55,030	7.35	22,250	8.98	7,945	2.68	5,077	19.29	1,525	6.31	15,496	5.46	5,474	13.96

Note: Landings indicate the sum of sampled fishing trips. Prices come from Chioggia Fish market.

shocks in contributing to production shortfalls from the frontier (Ogundari and Akinbogun, 2010). Second, a likelihood ratio (LR) test comparing the Cobb Douglas production function with the more comprehensive Translog specification was performed. The LR statistics of 46.44 (value model) and 34.45 (weight model) imply that the null hypothesis ($\alpha_{TT}=\alpha_{KWKW}=\alpha_{TKW}=0$) is rejected ($p$-value < 0.01), hence a flexible model including interactions among inputs and relaxing the restrictive Cobb Douglas assumptions is a better representation of the production process taking place in the fishery for both the weight and value specifications[2] (Kirkley et al., 2003). Third, testing for the influence of vessel-specific attributes on inefficiency, rejection of the null hypothesis ($\delta_Y=\delta_L=0$), indicates that the formulation of the stochastic frontier is more appropriate than a truncated normal model with mean δ_o (Greenville et al., 2006) for both Model 1 (output as kg of fish) and Model 2 (output as € of fish). The results of the likelihood ratio tests are shown in Table S2.

The mean efficiency scores for the value and weight-based models are 0.647 and 0.651, respectively, with the dominance of landings-based scores being most pronounced in October and November (Tab. 4). This difference, although small, suggests that on average Model 1 scores are higher than Model 2 scores, as confirmed by the Wilcoxon signed rank test on the equality of distributions (z-statistic = −2.925, p-value < 0.01) This confirms the importance of performing an efficiency analysis relating inputs and output in the production process of the fishery, since the intermonth comparison of revenues generated by landings provides only a partial representation of the profitability of the sector. A Kruskall-Wallis test reveals that the difference between value-based and weight-based scores is significantly different among vessels ($\chi 2$ (30) = 407.835, p-value < 0.01), hence indicating heterogeneity in the ability of fishers to capitalize on revenue opportunities from fishing activity. Overall, we highlight the potential of our analysis to provide a comprehensive assessment of the economic performance of the fishery by simultaneously *i*) following the evolution of efficiency scores throughout the year and *ii*) juxtaposing weight-based and value-based scores from Model 1 and 2, respectively. For instance, while the month of October may look as a profitable period due to the increase in landings (90,641 kg) and revenues (730,048 €) after the Summer ban (e.g. 57,236 kg of landings and 423,098 € of value in July) (Tab. 2), the intense fishing activity characterized by long time at sea and great fuel consumption (Tab. 5) leads to a greater usage of production inputs which negatively impacts the overall efficiency of the fishery.

[2] The test statistic is given by $LR=-2\,[\ln(L\,\{H_0\})-\ln(L\,\{H_1\})]$, where $\ln(L\,\{H_0\})$ and $\ln(L\,\{H_1\})$ are the maximized log-likelihood values under the null and alternative hypothesis, respectively. This is chi-squared distributed, with the degrees of freedom equal to the number of restrictions imposed. Critical values for testing the restrictions are taken from Kodde and Palm (1986).

Table 3. Maximum likelihood estimates of the parameters of the stochastic frontier models.

Parameter	Model 1 Weight as dependent variable	Model 2 Value as dependent variable
Frontier		
ln *kW*	8.282***	6.625***
	(−4.94)	(−4.11)
ln *T*	1.063**	0.975**
	(−2.26)	(−2.17)
ln *kW* * ln *T*	−0.25	−0.24
	(−1.58)	(−1.63)
$(\ln kW)^2$	−1.409***	−1.115***
	(−4.75)	(−3.92)
$(\ln T)^2$	0.0412**	0.0870***
	(−2.04)	(−4.56)
February	−0.204***	−0.142**
	(−3.38)	(−2.47)
March	−0.410***	−0.216***
	(−6.54)	(−3.60)
April	−0.341***	−0.249***
	(−5.51)	(−4.23)
May	−0.413***	−0.309***
	(−6.57)	(−5.12)
June	−0.534***	−0.527***
	(−8.31)	(−8.57)
July	−0.559***	−0.439***
	(−8.40)	(−6.95)
September	−0.372***	−0.310***
	(−5.50)	(−4.81)
October	−0.376***	−0.283***
	(−5.91)	(−4.65)
November	−0.04	−0.188***
	(−0.59)	(−3.05)
December	−0.08	−0.09
	(−1.25)	(−1.58)
Constant	−18.70***	−12.04***
	(−3.89)	(−2.61)
Inefficiency		
ln A	28.40**	39.22
	(−2.38)	(−1.31)
Length > 24 m	−5.51	−3.14
	(−1.36)	(−0.59)
Constant	−139.0**	−205.80
	(−2.39)	(−1.30)
Log-likelihood	−2615.24	−2534.26
Lambda	9.6***	13.6***
	(9.43)	(5.57)

Note: Standard errors in parentheses.
** $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

While the choice of a unique output measure of efficiency analysis- monetary (i.e. value) or physical (i.e. weight)- is open to debate, the great fluctuations in the price of target species shown in Table 2 point out the need to understand the influence of fish supply and temporal factors. In this sense, the estimation results reported in Table 6 provide interesting insights concerning the behaviour of fish prices at Chioggia Market. First, the role of sold quantities seems to have a negative effect on price levels, as dictated by economic theory. This holds for six out of seven species under analysis (except for queen scallop), with mantis shrimp prices being highly responsive to fluctuations in quantity sold. This indicates that changes in the quantity of mantis shrimp available in the market have a substantial impact on its price. On the contrary, queen scallop stands out as an exceptional case within the study, as it does not exhibit significant price elasticity.

Table 4. Technical efficiency distribution by month.

Month	*N*	Weight efficiency scores		Value efficiency scores	
		Mean	St.Dev	Mean	St.Dev.
January	234	0.663	0.163	0.659	0.166
February	251	0.648	0.178	0.651	0.173
March	222	0.655	0.170	0.652	0.169
April	233	0.650	0.170	0.649	0.166
May	252	0.637	0.186	0.636	0.184
June	217	0.638	0.190	0.636	0.191
July	184	0.648	0.186	0.650	0.189
September	174	0.656	0.175	0.650	0.187
October	216	0.645	0.186	0.636	0.201
November	202	0.661	0.160	0.652	0.178
December	211	0.656	0.180	0.650	0.188
Total	**2396**	**0.651**	**0.177**	**0.647**	**0.181**

Table 5. Monthly variations in fishing time and fuel consumption by sampled *rapido* vessels (year 2019).

Months		Fishing time (hours per fishing trip)	Fuel (litres per fishing trip)
J	Mean	24.0	1838.9
	St.Dev.	11.6	1137.9
F	Mean	22.6	1690.7
	St.Dev.	11.8	1113.7
M	Mean	19.3	1475.3
	St.Dev.	10.4	979.6
A	Mean	20.6	1553.6
	St.Dev.	11.3	1029.1
M	Mean	15.1	1120.6
	St.Dev.	8.0	739.7
J	Mean	17.7	1302.3
	St.Dev.	9.7	843.1
J	Mean	16.8	1226.4
	St.Dev.	8.3	809.7
S	Mean	15.9	1164.4
	St.Dev.	7.3	691.7
O	Mean	21.4	1543.0
	St.Dev.	10.3	936.3
N	Mean	17.5	1309.0
	St.Dev.	7.6	773.7
D	Mean	22.1	1698.6
	St.Dev.	10.9	1031.7

Nevertheless, the year 2020 demonstrates a stronger influence on queen scallop prices compared to other species.

Furthermore, a prominent pattern among various species is the tendency for prices to be higher at the start of the week (the opening day is Tuesday, as the market is closed on Sunday and Monday) and gradually decline towards the end. This presents a valuable opportunity for fishers to strategize their actions accordingly. Lastly, the influence of seasonality on fish prices plays a significant role in determining price fluctuations, since it reflects the changes in the availability of each stock, which can also be detected from Table 2. As an example, the relevant volumes of great Mediterranean scallop landed in Spring are associated to a negative and significant coefficient for the months of April, May and June. Nevertheless, we remark that the availability of longer time series of market prices would notably improve the robustness of our results, which consider only 2 yr (including the period affected by the COVID-19 pandemic).

5 Discussion and conclusions

Depending on the priority weightings placed by management institutions (economic efficiency, stock preservation), this type of analysis can support the selection of the most appropriate temporal units for future regulations involving a reduction in fishing days. To ensure that these have no impact on market supply and do not result in the closure of established commercial circuits, it is essential to consider both the distribution of fishing time limitations throughout the year in addition to the fishing time reduction itself (Sánchez Lizaso et al., 2020). On the other hand, even if the introduction of quotas for demersal species has been traditionally rejected in the Mediterranean Sea due to the multispecies nature of most fisheries (Mulazzani et al., 2018)[3], it is reasonable to presume that setting a total allowable catch (TAC) for sole in the Autumn/Winter season would prevent the fall in prices that occurs in November (6.35 €/kg) and December (6.89 €/kg), especially considering that sole represents about 50% of landings in these months. Similarly, transferring effort restrictions to periods characterized by lower efficiency (e.g. May, June, October) can improve the economic performance of the fishery by means of *i*) reduced inputs usage and *ii*) higher prices arising from the reduced fish offer in the market.

[3] A relevant exception is represented by the recent introduction of catch limits for red shrimp and blue and red shrimp in the Levant Sea (Recommendation GFCM/45/2022/7).

Table 6. Effect of quantities, day of the week, month and year on the price of main species.

Parameter	Sole		Cuttlefish		Murex		Caramote prawn		Mantis shrimp		Queen scallop		Great Med. scallop	
	coef.	*p*-value	coef.	*p*-value	coef.	*p*-value	coef.	*p*-value	coef.	*p*-value	coef.	*p*-value	coef.	*p*-value
Q	−0.03	*0.018*	−0.02	*0.004*	−0.04	*0.000*	−0.06	*0.000*	−0.13	*0.000*	0.00	*0.959*	−0.08	*0.000*
DW (ref: Thu)														
Tue	0.09	*0.000*	0.09	*0.001*	0.01	*0.658*	0.04	*0.076*	0.17	*0.000*	0.01	*0.814*	0.03	*0.203*
Wed	−0.01	*0.723*	0.01	*0.563*	−0.02	*0.325*	−0.03	*0.094*	−0.03	*0.404*	−0.10	*0.015*	−0.05	*0.017*
Fri	0.00	*0.901*	0.01	*0.794*	0.00	*0.767*	−0.03	*0.176*	0.02	*0.454*	−0.08	*0.059*	−0.02	*0.352*
Sat	−0.09	*0.015*	−0.01	*0.659*	−0.15	*0.000*	−0.09	*0.001*	−0.03	*0.426*	−0.31	*0.000*	−0.18	*0.000*
M (ref: Jan)														
Feb	0.11	*0.001*	0.05	*0.055*	−0.03	*0.168*	0.04	*0.261*	0.21	*0.000*	−0.10	*0.152*	0.08	*0.072*
Mar	0.17	*0.010*	0.09	*0.022*	−0.11	*0.014*	0.22	*0.000*	0.26	*0.000*	0.04	*0.707*	−0.05	*0.385*
Apr	0.11	*0.006*	0.01	*0.859*	−0.15	*0.000*	0.33	*0.000*	0.04	*0.435*	0.00	*0.966*	−0.09	*0.023*
May	0.11	*0.014*	0.07	*0.011*	−0.15	*0.000*	0.32	*0.000*	0.11	*0.009*	−0.05	*0.559*	−0.06	*0.097*
Jun	0.10	*0.001*	0.23	*0.000*	−0.05	*0.083*	0.23	*0.000*	0.14	*0.000*	−0.09	*0.202*	−0.14	*0.001*
July	0.07	*0.082*	0.56	*0.000*	−0.07	*0.006*	0.25	*0.000*	−0.11	*0.028*	−0.05	*0.390*	0.06	*0.243*
Aug	0.33	*0.000*	0.44	*0.065*			0.33	*0.000*	0.15	*0.002*				
Sep	0.02	*0.687*	0.11	*0.000*	−0.06	*0.092*	0.17	*0.000*	−0.23	*0.004*	−0.20	*0.015*	0.16	*0.000*
Oct	0.07	*0.047*	0.05	*0.146*	−0.13	*0.000*	0.09	*0.021*	−0.04	*0.423*	−0.17	*0.022*	0.10	*0.023*
Nov	−0.18	*0.000*	−0.05	*0.083*	−0.28	*0.000*	0.01	*0.700*	−0.21	*0.000*	−0.15	*0.045*	0.16	*0.005*
Dec	−0.11	*0.002*	0.11	*0.002*	−0.18	*0.000*	0.21	*0.000*	−0.03	*0.648*	0.12	*0.294*	0.31	*0.000*
Y (ref: 2019)														
2020	0.03	*0.154*	0.08	*0.000*	−0.16	*0.000*	0.00	*0.860*	−0.12	*0.000*	−0.46	*0.000*	0.02	*0.280*
Const	2.43	*0.000*	2.28	*0.000*	1.81	*0.000*	3.04	*0.000*	2.87	*0.000*	2.00	*0.000*	2.82	*0.000*
Obs	481		447		408		427		485		405		404	

Source: 2019 and 2020 daily prices from Chioggia Fish Market.

Moreover, inspection of Table 4 reveals that landings and value efficiency scores move in the same direction from month to month, meaning that increases (or decreases) in the former are usually reflected by increases (or decreases) in the latter. This suggests that fishers have a limited ability to adapt to changing prices through strategic behaviour while they tend to be greatly affected by changes in stock availability. Nevertheless, we remark that it is essential to further extend the analysis considering the biological cycles of target species, such as reproduction periods and areas, when contemplating any shift of fishing days from less efficient periods to more productive ones. The increasing use of georeferenced data describing fishing activity (Russo et al., 2020) is a promising research field for the integration of biological and ecological aspects in the study of technical efficiency, since it allows the identification of fishing areas characterized by different levels of efficiency, therefore informing potential management interventions aimed at spatially allocating fishing effort.

With reference to the intermonth comparison of efficiency scores, it is worth highlighting that the average October value-based score is indeed lower if compared to *i*) the months of September and November- which are both characterized by reduced inputs usage – and *ii*) its weight-based score monthly counterpart from Model 1. This reminds us of the well-known “race to fish” problem at the start of a new fishing season, an unintended consequence arising from effort restrictions involving temporal closures (Colwell et al., 2019). It is also worth noticing that the negative coefficient associated to the age of the *rapido* seems to affect efficiency estimates only in Model 1, meaning that- holding constant all other variables- older vessels are not necessarily less efficient in generating value during a fishing trip. The discrepancy between the two models might reflect the influence of other factors not included in the present analysis, like technological developments on board or skipper skill (Pascoe and Coglan, 2002), both of which are more difficult to regulate and monitor.

As already mentioned in the presentation of Table 6, further analysis investigating quantity-price relationships in the fishery would benefit from the inclusion of more recent data. This would be especially relevant in the case of queen scallop, which is the only species that does not show a significant elasticity. The reasons behind this observation warrant further exploration. For instance, this anomaly might be attributed to an oversupply in the market, potentially influenced by external factors such as the COVID-19 pandemic[4].

Further refinements of our analysis might take into consideration different approaches concerning the treatment fish stock fluctuations and their incorporation into the production frontier. The solution adopted here is to control for the influence of seasonal variations in fish availability using dummies (Pascoe and Robinson, 1998; Fousekis and Klonaris, 2003; Vinuya, 2010). Another approach would be to use information from stock assessments, but this is not available

[4] Another contributing factor can be related to trade dynamics. In 2020, Italian imports of frozen scallops, including queen scallops and other varieties, increased compared to the previous year, as reported by the Italian National Institute of Statistics (COEWEB, 2023). This surge in imports could have added to the supply of queen scallops in the market, potentially contributing to the price decrease observed in 2020.

for all the seven species under analysis at weekly or monthly level during the year 2019. Efficiency studies that include spawning stock biomass data among the control variables are usually based on longer time series at the yearly level (Yang et al., 2017). Alternative approaches include the computation of indexes of stock abundance based on relative catch rates (Pascoe and Tingley, 2007).

Lastly, we recommend that future research should investigate the expected economic effects following the implementation of a TAC system in the fishery. Intuitively, setting a TAC in the initial month following the fishing closure, it is expected that prices increase. Similarly, as the stock does not deplete immediately and is carried over to the subsequent month, there is a surplus stock in the sea, potentially leading to higher efficiency but lower prices in the following month. Therefore, we suggest that future studies should incorporate similar simulations to comprehend how maximum profits can be achieved while keeping catch levels constant. Considering the complexities involved in such a system involving both output and input restrictions, additional examination of the feasibility of a system of Individual Transferable Quotas (ITQs) deserves attention (Mulazzani et al., 2018). Furthermore, our findings suggest that there may be room for optimizing the volume and value of landings by considering more flexible scheduling of fishing days. For instance, allowing fishers to choose the fishing days throughout the week, rather than adhering strictly to the current weekend restrictions, or dividing the 6-week summer ban into alternative time periods. However, it is essential to acknowledge that the feasibility of such scheduling adjustments must be carefully evaluated by biologists and experts in fisheries management, especially considering the complexities linked to the selection of a seasonal fishing ban in multispecies fisheries. Indeed, stock assessment forms by the General Fisheries Commission for the Mediterranean (GFCM) indicate that there is limited concurrence in the reproductive season of relevant species like sole (Fall-Winter), cuttlefish (Spring-Summer), spottail mantis shrimp (Winter-early Spring), murex (June-July) and caramote prawn (Spring-Summer) in the GSA 17- which implies that any temporal modifications of the fishing season should take into account the current stock status and characteristics of the species involved. These potential reforms could offer a valuable avenue for enhancing the sustainability and profitability of the Chioggia *rapido* fishery while maintaining a balance with ecological considerations. Similar considerations were investigated by Russo et al. (2017) in their analysis of alternative management scenarios of demersal fisheries in Ionian Sea, where the adoption of seasonal and differentiated (rotated) fishing bans for trawlers- coupled by a temporal stop for small-scale fleets- led to positive effects both from a biological (i.e. increase in spawning stock biomass) and economic (i.e. rise in revenues) perspective. As the use of the BEMTOOL platform allowed the authors to model and forecast the long run effects of different management trajectories, our short-term analysis could be further enriched in a bioeconomic framework.

In summary, we highlight the potential of integrating efficiency and price formation analysis to understand whether there are any missed opportunities to generate value in the *rapido* fishery. Moreover, this type of study can be also replicated in other contexts, in order for fisheries management policies to address the specific socio-economic conditions of the coastal communities involved. While the biological dimension is not considered in this article, our investigation can provide a practical starting point to plan potential reforms of fisheries management in the GSA 17 from an economic perspective. Similarly, the proposed methodological approach has the potential to inform those policies requiring the use of multidisciplinary tools, such as the implementation of Marine Spatial Planning in Italian waters (Manea et al., 2019; Menegon et al., 2023). Furthermore, the influence of market dynamics in shaping the economic efficiency of the fishing sector, as revealed in this study, underscores the necessity for renewed market regulation and organization, wherein a significant role could be played by Producer Organizations (European Commission, 2023a). Considering the overexploitation condition of several stocks in the Mediterranean Sea, including the GSA 17 (FAO, 2023), we stress the relevance of promoting an ecosystem-based approach to fisheries management that takes into account both socio-economic and environmental concerns (Long et al., 2015; European Commission, 2023b). If on the one hand it is argued that the former dimension has been experiencing a historical disregard by European fisheries management (Cardinale et al., 2017; Carpi et al., 2017; Drouineau et al., 2023), major challenges posed by ecosystems degradation, climate change and arrival of alien species (Strafella et al., 2015; Grilli et al., 2020; Domina, 2021) require future policies in the Northern Adriatic Sea to gain support from a wide range of stakeholders, fishers included. In accordance with the biological needs of the species targeted by *rapido* trawlers, the allocation of fishing opportunities during the year based on efficiency and market trends can be a first step in this direction. Recently developed initiatives and studies aimed at assessing the socio-economic impacts of management interventions in the Mediterranean Sea (Prellezo and Villasante, 2023) and strengthening fishers' participation in decision-making processes (Malvarosa et al., 2023) indicate the potential for broad stakeholder engagement and increased involvement of the fishing industry.

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Data availability statement

The data that has been used is confidential.

Supplementary material

Table S1. Results of statistical tests for the price model (source: 2019 and 2020 daily prices from Chioggia Fish Market).

Table S2. Model specification tests.

The Supplementary Material is available at https://www.alr-journal.org/10.1051/alr/2024006/olm.

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