**Eliminating Competition in Fisheries Management: The Mediterranean case**

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**Abstract**

In this paper, we introduce a simple regulation scheme that might counteract the inefficiencies caused by competition between vessels in fisheries. Each fishing firm is induced to solve the same problem as a social planner. Without any regulation and a constant price for fish, a monopoly firm having all fishing rights might select the Maximum Economic Yield (MEY) outcome while competition between many vessels will create a competitive game where the solution is a Nash equilibrium comparable to the open access solution. With few vessels the outcome has similarities with the classic Cournot-Nash equilibrium of oligopolistic competition.

**1 INTRODUCTION**

In recent decades, incentive adjusting approaches such as individual quotas have become the preferred way of managing fisheries rather than incentive block approaches, including effort controls. This is because such instruments may achieve outcomes that are socially efficient. A large number of fisheries are today managed by tradeable quotas (Bjørndal & Munro, 2012). Nevertheless, many fisheries worldwide are still managed by input controls. Instruments include control of the number of vessels, days per vessels, technical characteristics and more. There are several reasons for that. One is because individual quotas may not function well in multispecies fisheries, e.g. in the tropics, where a very large number of species may harvested at the same time[[1]](#footnote-1). Another reason may be the difficulty of monitoring harvests while one or more aspects of inputs may be controlled much more easily. Examples include industrial fisheries such as those of the Falkland Islands but also many small scale fisheries. The case study we will consider in this article, multi-species demersal fisheries in the Mediterranean, are an example of the latter.

Assuming a fixed price a monopoly firm with all fishing rights would select the Maximum Economic Yield (MEY) outcome, the solution which is preferred by the social planner. Fisheries with full competition will result in an outcome that corresponds to open access (Bjørndal & Munro, 2012). Between these extremes we can find an outcome based on an assumption akin to the one used in traditional Cournot analysis (e.g. Tirole 1997). Here, in a one-product market, each oligopoly firm maximises its profit given that it knows the quantity produced by other firms. In this situation more firms will increase social welfare. In the open fishery case with few vessels, a similar assumption is that each vessel maximises profits by selecting its effort given that it knows the effort undertaken by all other vessels in the fishery. In this case, more vessels make competition greater which might significantly decrease social welfare. The reason, of course, is that the competition implies higher total fishing effort and therefore the fish stock diminishes because of overfishing. Whether this happens depends on the ability of the fisheries manager to eliminate the competition element.

In this paper, we fill a gap in the theory of fishery regulation by assuming a payment function where fishers’ profits are independent of other participants in the fishery. In that case, when we use a simple static Gordon-Shaefer model as an example, every vessel will choose an efficient effort level. This payment function depends on an effort share parameter assigned to vessel *i* and the effort it chooses. The mechanism might be interpreted as an individual tax being levied on each vessel that only depends on an individual effort share parameter and of its own aggregated effort during the regulation period.

**2 THE BIOECONOMICS MODEL**

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We base the analysis on the static Gordon-Schaefer bioeconomic model (Bjørndal & Munro, 2012). Moreover, we assume steady state so that there is no change in stock size x, i.e.,

where is the growth function, and is catches given as a function of stock size and of total effort (e). Solving this equation with regard to , and eliminating the solution, gives the stock function, where as stock declines in effort. With the Schaefer harvest function (Schaefer, 1957), we have

where is a constant, known as the catchability parameter. Further, assuming constant price and variable costs for each unit of effort, we have profits as:

This formulation also describes the profit of a sole owner fishery where all fishing rights are held by one firm. The concavity ensures an inner solution to (3). The optimal solution is called the maximum economic yield (MEY) level. As the social planner optimises the same objective function, the outcome of (3) is efficient.

To find an analytical expression, we use the logistic natural growth equation,

where is the intrinsic growth rate and the carrying capacity of the environment. Assuming steady state (eq. 1), for , the stock-effort relationship becomes

When (5) is inserted in (3), we find the sole owner problem as

The first order condition becomes

which gives

where denotes the effort of the sole owner.

Next, consider the case with independent and equal vessels in the fishing industry. Each vessel simultaneously and independently chooses effort in the one-stage game by maximising its profit given that the vessel has knowledge about the sum of effort chosen by other firms. Vessel ’s profit becomes

where is one of the other equal vessel’s effort multiplied with the number of other firms, . The first order condition is

Using (5), the solution is the reaction function

As firms are equal, we can replace in (11) with and solve the resulting equation with respect to , i.e.,

If , total effort is

which corresponds to the open access solution.

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There are fishery firms, each assumed to control one vessel, which can be regulated via a mechanism suggested by Berglann (2012)[[2]](#footnote-2). Berglann (2012) considers regulation in a static model with negative externalities caused by pollution. We do the same by treating a dynamic fishery model in a static context. The outcome is a mechanism where revenues become regulated on an individual basis. The revenue increases until effort is over a certain point (the maximum economic yield, MEY), thereafter it decreases as individual effort increases through the regulation period.

The following equation differs slightly from (9), because we want to indicate that information might be asymmetrically distributed. We restate (9) as

where *n, p* and *q* are commonly known, and and are choice variables. The (dash above) marking indicates, as assumed in Berglann (2021), that the information about the stock size function , and hence also the revenue , is not known by the planner but only known or experienced by the vessels. The latter because vessels see the relationship between effort and harvest as they fish and they observe the sum of effort of opponents.

Now, let us assume that the planner applies available historical data to estimate model parameters, including the stock-effort relationship in equation (5). Regulation then take place as follows: Before fishing starts, parameters of the modelled stock function are disclosed and becomes common knowledge. The planner promises that parameter values will not be updated during the regulation period, and thereafter, each vessel in the industry is informed that its revenue for landed fish will be

where is the amount of effort chosen by the vessel. The parameter can be interpreted as firm ’s holding of share permits, or its allocated share of the total expected effort chosen by the industry, where the total is . Note that the latter interpretation of might be a little misleading. It is only a parameter in the individual revenue function (15) rather than a unit of permissible effort. It turns out to map into the firm’s share of total effort only if all firms behave optimal. But in no way the parameter restricts the vessel owner from choosing more or less effort than the given share of the total.

If the planner were in the possession of adequate information to perfectly foresee the relation between the ex post optimal efforts of vessels, he/she would be able to portion out optimal holdings. That will be situation in the "*n* equal vessels" case, which yields for all *i*. The result of applying the revenue schedule (15) to each firm would be a series of optimal choices within the industry.

The first order condition of (15) minus costs, , using (5) is

which solves to the effort of the sole owner (8) times

This may give the optimal total effort promoted by a social planner that may also be distributed between vessels in an optimal way. We see this by summing up shares , where we get in (8), i. e. the effort chosen by the sole owner. Individual profit under optimal effort becomes

**3. THE MEDITERRANEAN CASE**

Mediterranean fisheries are a case in point when it comes to effort or input management. These fisheries are managed by controlling input through effort limitations and technical restrictions, contrary to other EU fisheries that are regulated by catch quotas (output controls) (Lleonart and Maynou 2003). This fisheries management model was enshrined in the EU Common Fisheries Policy (CFP) as the “Mediterranean specificity” (EU 2006) and has contributed to determine the non-adaptive character of fisheries management in the region (Penas Lado 2016); that is, fishing effort is not annually revised to meet some specified optimality criterion. The lack of annual revision of fishing effort to match existing fishing opportunities has led to an excessive harvest, overcapacity and economic inefficiencies (Vielmini et al. 2017; Gómez and Maynou 2020). To redress these problems, the EU has established subregional Multi-Annual Plans (MAP) to align fishing effort with fishing mortality at maximum sustainable yield (MSY) for the main fish stocks within a specified time frame, as envisaged in the 2013 reform of the CFP (EU 2013). For instance, in the Western Mediterranean, a MAP for demersal resources aims at reducing effort with 40% by the end of 2024 compared to actual days for 2016-18 by setting the number of fishing days per fleet segment (COM/2018/0115 final – 2018/050 (COD)).

Thus, the problem of effort shares is very pertinent, particularly in the Mediterranean multi-annual plan where the total effort available (days/year) is now being allocated by individual vessel, according to some historical values as "effort shares", . In retrospect the total effort may have been set too high.

The objective of the Western Mediterranean Multi-Annual Management Plan (WM MAP) is to achieve (Fmsy) by 1st Jan. 2025 for the main five target species European hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), Norway lobster (*Nephrops norvegicus*), deep-water rose shrimp (*Parapenaeus longirostris*) and red shrimp (*Aristeus antennatus*).

Our case study models demersal fisheries in the NW Mediterranean, focusing on geographical subarea GSA06 (the Mediterranean coast of Spain[[3]](#footnote-3)). Demersal fisheries are exploited mainly by otter bottom trawl (about 80% of demersal landings), with fishing vessels of 14 - 28 m length overall based on the 40 fishing harbours (578 vessels were active in 2019).

The five main stocks that define the policy objective make up 48% of the landings of the demersal fishery, the remainder comes from dozens of other secondary species (see Akbari *et al*., 2021). For this reason and for model simplicity we are treating the stock as aggregate here.

The model was parameterised from data for the bottom trawl demersal fishery in GSA 06, available for the period 2008-2016 in STECF (2020) and complemented with our own data for 2017-2019 obtained by interviews of vessel skippers (Gómez and Maynou 2020). The parameters of the biological submodel were estimated with ASPIC 7 (Prager et al. 1996) and are given in table 1. The combined carrying capacity of the stocks harvested by this fleet is 19,900 tonnes with the instrinsic growth rate estimated at 2.5. This implies that the stock level giving rise to maximum sustainable yield is 9,950 tonnes with MSY equal to 12,473.5 tonnes.

In 2019, the fishing fleet consisted of 578 vessels, each operating between 120 and 190 days, on average 155 days. Thus, total effort in days was 89,590. Total catches were 10,640 tonnes. Table 1 shows also price, costs and production estimated for 2019.

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| --- | --- | --- |
| Table 1: Parameters for the NW Mediterranean demersal fishery exploited by otter bottom trawl | | |
| **Fleet size (2019)** | 578 | vessels |
| Individual effort level (number of fishing days) | 120 -190 | days / year |
| Mean individual effort (number of fishing days) | 155 | days / year |
| Harvest | 10,640 | tonnes |
| Biological production function (Schaefer model) | | |
| K | 19,900 | tonnes |
| R | 2.5 |  |
| q = 0.00397 (tonne/year)/155 = | 2.56 10-5 | tonne/day |
| **Economic parameters** |  |  |
| price of fish | 9,472,5 | €/tonne |
| costs per unit effort: |  |  |
| Fuel | 240 | €/day |
| labour costs | 438,7 | €/day |
| other variable costs | 319 | €/day |
| Total variable costs | 997.7 | €/day |
| Fixed costs | 69.0 | €/day |
| total costs per unit effort | 1066.7 | €/day |
|  |  |  |

In figure 1 we illustrate total revenue and total costs, both as functions of total effort, for the demersal fishery under consideration, based on the parameters given in table 1 for the estimated Gordon-Schaefer model. We find that =48,804 days, =38,021 days and = 76,042 days. , which gives maximum profits, and compare to an actual effort of almost 89,590 in 2019. Actual effort is even larger than , This clearly illustrates the need for a reduction in effort.

For 2019, it is seen that the difference between revenues (dot, red) and costs (dot, blue) is just over € 5.2 million. Actual stock level in 2019 is estimated at 4,378 tonnes. This is, however, a disequilibrium situation. Inspection of figure 1 will, however, show that in equilibrium, there will be substantial losses at this effort level (vertical dotted line). In equilibrium, harvest is 3,751 tonnes, stock size 1,635 tonnes and there is a negative profit of € 60 million. A situation like this can only be supported by substantial subsidies.

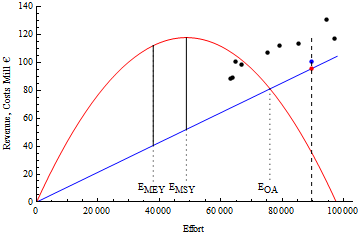


Figure 1: Total costs (blue curve) and revenues (red curve) as a function of total effort in the single species Gordon-Schaefer model of the NW Mediterranean demersal fishery. The blue and red coloured dots are respectively revenues and costs in 2019. The black dots are observed revenues at observed effort levels from 2008 to 2018.

The various alternatives, in terms of number of vessels, total effort, harvest, stock size and profit are illustrated in table 2. Scenario 1 is the 2019 situation but as noted, this is a disequilibrium. For the 2019 harvest of 10,640 tonnes to be in steady state, effort per vessel would have to be reduced from 155 to[[4]](#footnote-4) . In other words, reducing effort with 25% (scenario 2) would be sufficient to obtain the same landings and but with a profit of 28.8 million € which is more than five times larger than at the present because of less use of costly effort. Equilibrium stock size in this case is 6,160 tonnes.

Scenario 3 represents the current effort reduction plan to reduce current effort by 40%. Once equilibrium is reached, this would involve a more than doubling of the stock size to 8,941 tonnes, an annual harvest of 12,310 tonnes and annual profits of € 59.2 million.

The other scenarioes (4-9) of table 2 shows the outcome with free fishing but when a limited number of firms are allowed to participate in the fishery. Scenario 4 and 5 describes the outcome with a fixed price when all fishing rights are held by one firm, respectively in the case when the firm has MEY and MSY objectives. The MEY is the social planner’s preferred solution. Scenario 6 shows the outcome in the duopoly case, i.e. when the fishery is open and two independent firms are given the fishing rights. The oligopoly scenario 7 and 8 have respectively n=10 (arbitrary chosen) and n=578 (vessels in 2019) number of fishing rights in use. In these scenarios (6-8) fishing firms do include own effort costs in their calculations. Firm chooses effort determined by equation (12) which is the effort that maximises its equilibrium profit given the sum of effort for all other firms. Scenario 9 shows the full competition or open access case (corresponding to ). Here total effort is given by equation (13). In general, we see, for , that the solutions will not be efficient.

Table 2: Outcomes for the NW Mediterranean demersal fishery by the otter bottom trawler fleet in GSA06 when each of vessels maximise its profit given the sum of effort for all other fishers. In alle these cases we calculate with total costs per unit effort = 1066.7 €/day

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Scenario | Number of fish rights, *n* | Total effort  days | Total harvest  tonnes | Stock size  tonnes | Total profit  mill € |
| 1 | Realised (2019) | 578 | 89,590 | 10,640 | 1,635 | 5.20 |
| 2 | 25% effort reduction | ≤578 | 67,395 | 10.633 | 6,160 | 28.8 |
| 3 | 40% effort reduction | ≤578 | 53,754 | 12,310 | 8,941 | 59.2 |
| 4 | MEY | 1 | 38,021 | 11,830 | 12,148 | 71.5 |
| 5 | MSY | 1 | 48,804 | 12,438 | 9,950 | 65.7 |
| 6 | Duopoly | 2 | 50,695 | 12,419 | 9,564 | 63.6 |
| 7 | Oligopoly | 10 | 69,129 | 10,280 | 5,806 | 23.6 |
| 8 | Fleet size (2019) | 578 | 75,911 | 8,600 | 4,423 | 4.9 |
| 9 | Full competition |  | 76,042 | 8,563 | 4,396 | 0 |

As we pursue in this article, instead of setting effort quotas for each vessel equal to a specific number of days, an alternative to achieve optimal total effort can be by regulating individual revenues, equation (15). Using equation (17) and parameter values of table 1, we find that regulation with equilibrium as a goal, vessel ’s effort in equilibrium becomes a share of the effort chosen by the sole owner firm (and the planner)

where is the total effort equilibrium goal, e.g. at MEY , is the effort share set by the regulator. Since , we find that the wanted outcome is achieved when s=1 (with *n* equal vessels, for all *i* ). Figure 2 shows profit as a function of effort for a vessel in this case (red curve). In optimum individual effort is 65.8 days (=38021/578 days) and vessel profit (18) is 0.124 mill €.

The interpretation of as a share of total effort might not be necessary. In scenario 5, for the fishing industry to choose to attain the MSY target, a value might be requested. In this case ’s can not be interpreted as shares because their sum becomes larger than one, in this case . The blue curve in Figure 2 shows a vessel’s profit in this MSY scenario. For vessels to choose a 48804/578 = 84.44 days effort level, with an individual profit (18) of mill €, an extra amount of subsides are required. This subsidy can be regained for example with levying a profit tax making the net profit inverse proportional to , i.e. that 0.124 mill € which is equal to the MEY profit.

If the total effort goal in equilibrium is a 40% reduction of the 2019 effort level (Scenario 3) at 53754. That level may be targeted with a value equal to . The orange curve in Figure 2 shows a vessel’s profit in this scenario 3. Optimal vessel effort and gross profit is respectively 93.0 days and 0.175 mill €.

Similarly, scenario 2, showing a 25% reduction leads to . The vessel’s profit curve in this case is colored green in Figure 2. To attain that 53754 level an extra amount of subsides are required. Optimal vessel effort and gross profit is respectively 116.6 days and 0.219 mill €.



Figure 2. Profit under regulation in the above scenarios, for each of the n=578 vessels. Scenario 2 (25% reduction, green), scenario 3 (40% reduction, orange), scenario 4 (MEY, red) and scenario 5 (MSY, blue).

If vessels are heterogenous, e.g. there are two groups with each 578/2=289 vessels where costs differs by 10% and is thus in one group and in the other group. With the MEY target each group is appointed similar effort shares , then and that adds to . With a 40% reduction target we set , and when costs differs by 10% then days and days that adds to .

These latter calculations show by example that flexibility of the regulation in no way restricts the vessel owner from choosing more or less effort than the given share of the total allowable effort (TAE).

A PANDORA toolbox application.

It might be possible to create simulations of Mediterranean fishing with heterogeneous fishing vessels and construct a one player game. Different costs are assigned to various vessel groups. Fishers automatically maximize their profits, and a fisheries manager (the player) controls the total effort, , by turning on parameters.

**4. CONCLUDING REMARKS**

In general effort rights-based management might be more effective at managing fishing mortality where uncertainty in biomass and TAC estimates is more fundamentally important than uncertainty in the estimates of the catchability coefficient. (FAO 2012). The practical advantage of our proposal is that the build in flexibility may make it easier for the skippers to comply with the regulation and might, among other things, thus increase the legitimacy of the regulation.

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1. There are, however, many multispecies fisheries where individual quotas have been found to function very well. One example is given by the British Columbia groundfish fishery (Bjørndal & Munro, 2012). [↑](#footnote-ref-1)
2. Originally proposed by Loeb and Magat (1979) in the context of regulating the output of a monopoly. [↑](#footnote-ref-2)
3. For fishing areas, see <http://www.fao.org/gfcm/data/maps/gsas/en/>. [↑](#footnote-ref-3)
4. Solving with respect to yields

   with solutions and . [↑](#footnote-ref-4)