TAX-BASED FISHERIES MANAGEMENT:

THE CASE STUDY OF THE CANTABRIAN ANCHOVY FISHERY*

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Abstract

A dynamic optimisation framework is adopted to show how tax-based management systems theoretically correct the inefficient allocation of fishing resources derived from the stock externality. Optimal Pigouvian taxes on output *(τ)* and on inputs *(γ)* are calculated, compared and considered as potential alternatives to the current regulation of VIII division Cantabrian anchovy fishery. The sensibility analysis of optimal taxes illustrates an asymmetry between *(τ)* and *(γ)* when cost price ratio varies. The distributional effects also differ. Special attention will be paid to the real implementation of the tax-based systems in fisheries.

KEY WORDS: Fisheries; Piguvian taxes on catches; Pigouvian taxes on effort; VIIId Anchovy Fishery; Implementation.

JEL CLASSIFICATION: Q22, Q28.

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0. INTRODUCTION

Any commercial fishery may exhibit several types of externalities (i.e stock externalities, production externalities, price externalities, etc.; Munro & Scott (1985), Boyce (1992)). Nevertheless, the fundamental one derives from the resource base itself. The stock is a factor in each firm's production function. Thus, each fishing firm, by extracting from limited common pool resource (CPR), reduces the harvesting possibilities of other fishing firms. The result is a tendency towards excessive *fishing effort*[1] and overexploitation of the CPR.

To face the sub-optimal economic allocation resulted from the competitive utilisation of the fish stocks, different institutions (i.e. the state, the regulation agency, co-management groups, etc.) manage the fisheries, either with command and control direct regulation methods based on the limitation of the activity[2], with indirect methods trying to affect incentives on behaviours (i.e. taxes) or via the allocation or rights (for example Individual Transferable Quotas (ITQs))[3] (see Clark (1980), Arnason (1990) or Boyce (1992) for a solid theoretical overview. And Townsend (1992), Dupont (1991) and Grafton (1996) for empirical case studies and surveys). Although in this paper we are referring to tax-based systems it is worth mentioning that taxes and transferable quota prices are theoretically equivalent under perfect quota markets and in absence of uncertainty (Arnason (1990), Weitzman (2002), Hannesson & Kennedy, 2003).

Under fairly general conditions, individual fishing effort is a continuous, decreasing function of taxes. Thus, any desired path of aggregate fishing effort, including the socially optimal one, may be generated by choosing the appropriate tax rate. The drawback is that the calculation of the optimal Pigovian tax (i.e. the one

[1] Fishing effort is a composite measure of different production inputs. Technically it can be defined as a micro production function of factors including capital, fishing days and labours (Squires, 1987; del Valle et al., 2003).
[2] The restrictions can affect the inputs (fishing days, fishing capacity, mesh sizes, etc.) or outputs (Total Allowable Catches (TACs)).
[3] Or equivalent ones such us Individual Transferable Fishing Days (ITFDs), Individual Transferable Licenses (ITLs), etc.

guarantying maximum overall profits obtained from the fishery), requires to solve each firm's profit maximisation problem to estimate its particular effort-tax response function; as well as the overall profit maximisation problem (the so call sole *owner's problem*) to derive the socially optimal allocation and the social shadow value of the resource.

The case study of the VIII division anchovy fishery will be considered to undertake the empirical analysis based in the theoretical framework to be developed in section 1. The applied bio-economic optimisation model takes for granted the estimated parameters of the population growth, production and cost functions in del Valle et al. (2001). After detailing the implicit assumptions in the applied model, Section II includes the optimal taxes (both, on output and on input), the tax collection and the sensibility analysis related to cost price ratio and discount rate changes in two alternative scenarios: the short run one implying positive after tax net profits and the long run open access one characterised by zero net profits. Finally, section 3 summarises the main conclusions and derived economic policy recommendations.

1. THE THEORETICAL BACKGROUND

The fiction of the *sole owner* (Scott, 1955), either a *corporation* (Towsend, 1998), a regulatory agency or a benevolent social planner that owns complete rights to the exploitation of a given fish population (Clark, 1990), is usually adopted in the literature as the reference to address the efficient bio-economic allocation in a fishery (i.e the profit maximising stock (s^*), *fishing effort* (e^*) and catch levels (Y^*)). Thus, the *sole owner* is understood to solve an infinite horizon discounted aggregated profit maximisation problem, subject to the biological and technological constraints, internalising the social shadow value of the resource (μ) (see problem I in Appendix 1).

Assume that the price per tonne of fish harvested *(p)* and the social discount rate *(r)* are exogenous. $Y(e_i(t),s(t))$ and $C(e_i(t))$ are respectively the production function[4] and the opportunity cost of effort[5] for a representative fisherman i $(i=1,\ldots,N)$, while $G(s(t))$[6] is the population growth function[7]. The usual economic rule for the efficient allocation of effort derived from the necessary maximum equation (1) implies that, for every t and each of the i active fisherman, the value of the marginal productivity of effort (Ye_i) discounted by the social shadow current price (μ) equals the marginal cost of effort (Ce_i). The equilibrium shadow value of the resource (μ^*) (i.e. the one derived from $\dot{\mu}=0$) (2) can be directly obtained from its movement equation along the optimal path $(\dot{\mu})$.

$$\left[p-\mu(t)\right]\cdot Y_{e_i} = C_{e_i}, \quad for\ \forall\ t,i\,/\,e_i>0 \tag{1}$$

$$\mu^* = \frac{p\cdot\sum_i Y_s}{\sum_i Y_s + r - G'(s)} \tag{2}$$

There are two important details to put stress on when considering the individual behaviour of the firm seeking to maximize its own profits (see problem II in Appendix 1). For one side, there is some ambiguity in the fisheries economic literature concerning the individual firm's perception of the biomass growth function constraint. While in some cases (Clark, (1980), (1990)), individual fishermen are considered to take no notice of the effect their own harvesting might have on the future resource stock (i.e. private shadow values $\lambda_i=0$), in others (Arnason, 1990; Boyce, 1992), the argument that *rational* firms should take the appropriate notice of all the variables and relationships affecting their profit functions (including the resource growth constraint) is defended

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[4] $Y(e_i(t), s(t))$ is a quasi-concave production function of two production inputs, stock and fishing effort.

[5] $C(e(t))$ is concave and decreasing.

[6] $G(s(t))$, is assumed to be twice differentiable with a maximum value, commonly referred to as the maximum sustainable yield (MSY).

[7] $G(s(t))$, is assumed to be twice differentiable with a maximum value, commonly referred to as the maximum sustainable yield (MSY).

(thus, $\lambda_i \geq 0$). Any case, the structure of the *efficiency rules* linked to the social (I) and private problems (II) is equivalent. They only differ in the fact that in equation (3) the value of the marginal productivity of effort is reduced by the private shadow value (λ_i), instead its social value (μ) (1). Equation (4) captures the equilibrium value of (λ^*) (i.e. the one derived from $\dot{\lambda}=0$) for $\lambda_i>0$.

$$\left[p-\lambda_i(t)\right]\cdot Y_{e_i}=C_{e_i}, \quad for\ \forall\ t,i\,/\,e_i>0 \tag{3}$$

$$\lambda_i^*=\frac{p\cdot Y_{s_i}}{\sum_i Y_s + r - G'(s)} \tag{4}$$

Secondly, assuming an open access scenario characterised by no barriers on entry, the existence of positive individual profits may incentive new entrants. As a result, the number of firms (N) would not stop increasing until the *economic rent* of the fishery is completely dissipated. Thus, the long-term steady state competitive allocation of the industry is often identified with the one obtained from equalling p to average cost of fishing effort.

Putting side by side the aggregate competitive effort, stock and profit levels ($\tilde{e}, \tilde{s}, \tilde{\pi}$) with their optimal values (e^*, s^*, π^*), note that from equations (2) and (4) it is clear that, for the same s and e_i, the equilibrium social shadow value is at least as great as private one (i.e. $\mu^* > \lambda_i^*$ *for all i*). Furthermore, from (2) and (3) it follows that for a given equilibrium biomass, $\tilde{e} > e^*$ whenever $N>1$. It is straightforward to conclude that $\tilde{\pi} \leq \pi^*$.

Starting with the sub-optimal competitive allocation, Pigouvian taxes theoretically convert a situation of rent dissipation into one of rent capture. If the tax rate is set correctly, either on the output (harvest) itself (τ) (see problem III in Appendix 1) or on inputs (fishing effort) (γ) (see problem IV in the Appendix), the implicit rental value of the fishery resource will be maximised. Taxes involve either an increase of costs or a decrease on the net price of the harvest, which generates incentives to decrease the individual effort until $(e^*, s^*, Y)^*$ is achieved.

Comparing the efficiency rule associated with the sole owners' problem (1) with the related to the individual behaviour of the firm under a Pigouvian tax on harvests (5), it is simple to derive that the Piguvian tax on catches that guaranties the optimal allocation is $\tau_i^* = \mu - \lambda_i$[8]. Hence, equation (6) shows the value of τ_I^*.

$$[p - \lambda_i - \tau_i] \cdot Y_{e_i} = C_{e_i}, \quad for\ \forall\ t, i / e_i > 0 \tag{5}$$

$$\tau_i^* = \frac{p \cdot \sum_i Y_s - p \cdot Y_{s_i}}{\sum_i Y_s + r - G'(s)} \tag{6}$$

Similarly, the Pigouvian rate on effort that matches the maximum equation associated to the behaviour of the individual firm under a Pigouvian tax on inputs (7) with (1) is $\gamma_I^* = (\mu - \lambda_i) \cdot Y_{ei}$[9](8). So, in terms of equivalency $\gamma_i^* = \tau_i^* \cdot Y_{ei}$ holds.

$$[p - \lambda_i] \cdot Y_{e_i} = \gamma_i + C_{e_i}, \quad for\ \forall\ t, i / e_i > 0 \tag{7}$$

$$\gamma_i^* = \left[\frac{p \cdot \sum_i Y_s - p \cdot Y_{s_i}}{\sum_i Y_s + r - G'(s)} \right] \cdot Y_{e_i} \tag{8}$$

In an open access scenario the existence of positive profits may incentive new entrants even in presence of taxes. That is way the marginal productivity of effort in the maximum equations associated to (III) and (IV) is often substituted by the average productivity of fishing effort (Y/e), letting that way the calculation of the long run corrective taxes on catches $(\tau(\pi=0))$ and on effort $(\gamma(\pi=0))$ captured in (9) and (10)[10] (Surís (1993), Hannesson and Kennedy (2002)).

$$\tau_i[\pi = 0] = p - \frac{(p - \mu) \cdot Y_{e_i}}{(Y_i / e_i)} \tag{9}$$

$$\gamma[\pi = 0] = p \cdot (Y_i / e_i) - Y_{e_i} \cdot [p - \mu] \tag{10}$$

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[8] If $\lambda_i=0$, then $\tau_i=\mu$

[9] If $\lambda_i=0$, then $\gamma_i= \mu \cdot Y_{ei}$

[10] Cost minimising behaviour has been assumed.

Notice that the optimal tax is in general not uniform over firms. In fact, only if the firms are identical[11] *(i.e.* $\lambda_i=\lambda_j$*)* will there be a single optimal tax ($\tau=\mu-\mu/N$; $\gamma=(\mu-\mu/N)\cdot Ye$)[12]. Since bigger firms have generally higher λ_I (Arnason, 1990) the smallest firms would stand higher tax rates. This not only would tend to contradict widely held notions about fairness in taxation, it also might have somewhat disturbing socio-political implications.

Besides, the informational and technical requirements for determining the optimal tax are high. The tax authority should solve the social optimality problem (I) as well as each firm's individual maximisation problem (II) to calculate μ and λ_i for all i,. To be able to do so, the tax authority ought to have at its command all the data relevant to the fishing firms (i.e. the resource growth function, the harvesting and cost functions of all i and t). Moreover, the tax authority should continuously monitor the state of the resource and the movement of the relevant economic prices for the optimal tax must be continuously adjusted to new conditions.

3. CASE STUDY: THE VIIId EUROPEAN ANCHOVY FISHERY

The applied bio-economic optimisation model to solve problems I to IV in Appendix 1 is based upon the estimated parameters of the *Cushing population growth function* ($g(s(t))=a\cdot s(t)^b-s(t)$; $a=72.2549$, $b=0.645$), the aggregate *Cobb Douglas production function* ($f(s(t),e(t))=q0.319915\cdot s(t)^{\alpha}\cdot e(t)^{\beta}$; $q=0.319915$, $\alpha=0.68226$, $\beta=0.66822$*]* and the ratio *C(e)/p in del Valle et al.* (2001). The econometric estimation of a, b, α and β was undertaken from time series data (1966-95) of biomass (Uriarte, 1998), catch and effort (ICES) (see Appendix 2 and del Valle et al. (2001) for more

[11] Identical technology does not necessarily imply identical firms. Firms may be different sized.
[12] If $\lambda_i=\lambda_j$, then $\mu=N\cdot\lambda$, which implies $\Rightarrow \lambda=\mu/N$.

details). *C(e)/p* was derived from data of "Anuario Estadístico del Sector Agroalimentario" (1986-1995) and Caill (1995).

The lack of panel data at the vessel level in other to construct an individual index for the fishing effort to be used to estimate individual fishing technologies and cost functions obliged us to assume some simplifications. Firstly, the derived impossibility to estimate individual production functions was solved working in the aggregate level, which implies accepting identical and homogeneous vessels, and thus identical private shadow values for the resource. Secondly, the number of standardised vessels[13] was chosen to represent the aggregate effort level in the fishery[14]. Thirdly, as a result of the very limited length of the cost series to undertake a robust econometric analysis, the ratio *C(e(t))*/p was considered exogenous (c/p henceforth). Given that cost data were on an annual basis (disregarding the fact that many fisheries work seasonally) we estimated the proportion of total costs attributable to anchovy fishing, considering the time devoted to it. The value for c/p range between 40 and 100. Its average value is 70. For another side, a discount rate from 0,05 to 0,1 will be considered acceptable for the purposes of the study. Thus, BC = $\{c/p=70 \wedge r \in [0.05, 0.1]\}$ and BI = $\{c/p \in [40, 100] \wedge r \in [0.05, 0.1]\}$ will be respectively the base case (BC) and the reference base interval (BI) to address the empirical work.

Table 1 includes the optimal stock (s^*), fishing effort (i.e the number of vessels) (e^*) and catches (Y^*) for BC and BI. The mean (1966-95) period values of stock (s^{-}), number of vessels (e^{-}), and catches (Y^{-}) have also been included. Comparing the optimal with the real time series for stock, effort and catches, the affirmation that actual

[13] In spite that there are two different fleets operating with two different technologies (purse seines and pelagic trawlers), the few degrees of freedom linked with the short length of the time series (1986-1995) and the short quota share of the pelagic fleet made it not possible to obtain different production functions for each of the sub-fleets. Therefore, using a procedure similar to that of Sathiendrakumar and Tisdell (1987), we opted for an equivalence criterion, finally resulting one pelagic vessel to be equivalent of 1.59 purse seine.
[14] In schooling fisheries (like anchovy) searching for schools is an important activity. Accordingly, in such fisheries the number of participating vessels is often accepted to be an appropriate measure of effort.

evolution of the fishery is a long way from reaching economically optimal solutions stands. Stock is found to be well below what would be considered the optimal interval, the number of vessels is extremely high, and catch levels show signs of being unsustainable in the long term.

-Table 1-

Optimum (s^*, e^*, Y^*) and mean real reference values $(\bar{s}, \bar{e}, \bar{Y})$

	s^*	e^*	Y^*	$\bar{s}$	$\bar{e}$	$\bar{Y}$
BASE CASE [†]	[98,000 - 100,000]	[131 - 140]	[21,000]	50,898	412[†††]	29,798
BASE INTERVAL [††]	[78,000 - 115,000]	[90 - 222]	[18,000, 26,000]	–	–	–

Source: del Valle et al. (2001)

[†] BC={c/p=70 ∧ r∈ [0.05, 0.1]} [††] BI= {c/p∈[40, 100] ∧ r∈[0.05, 0.1]}

[†††] 412 standardised vessels = 386 real vessels.

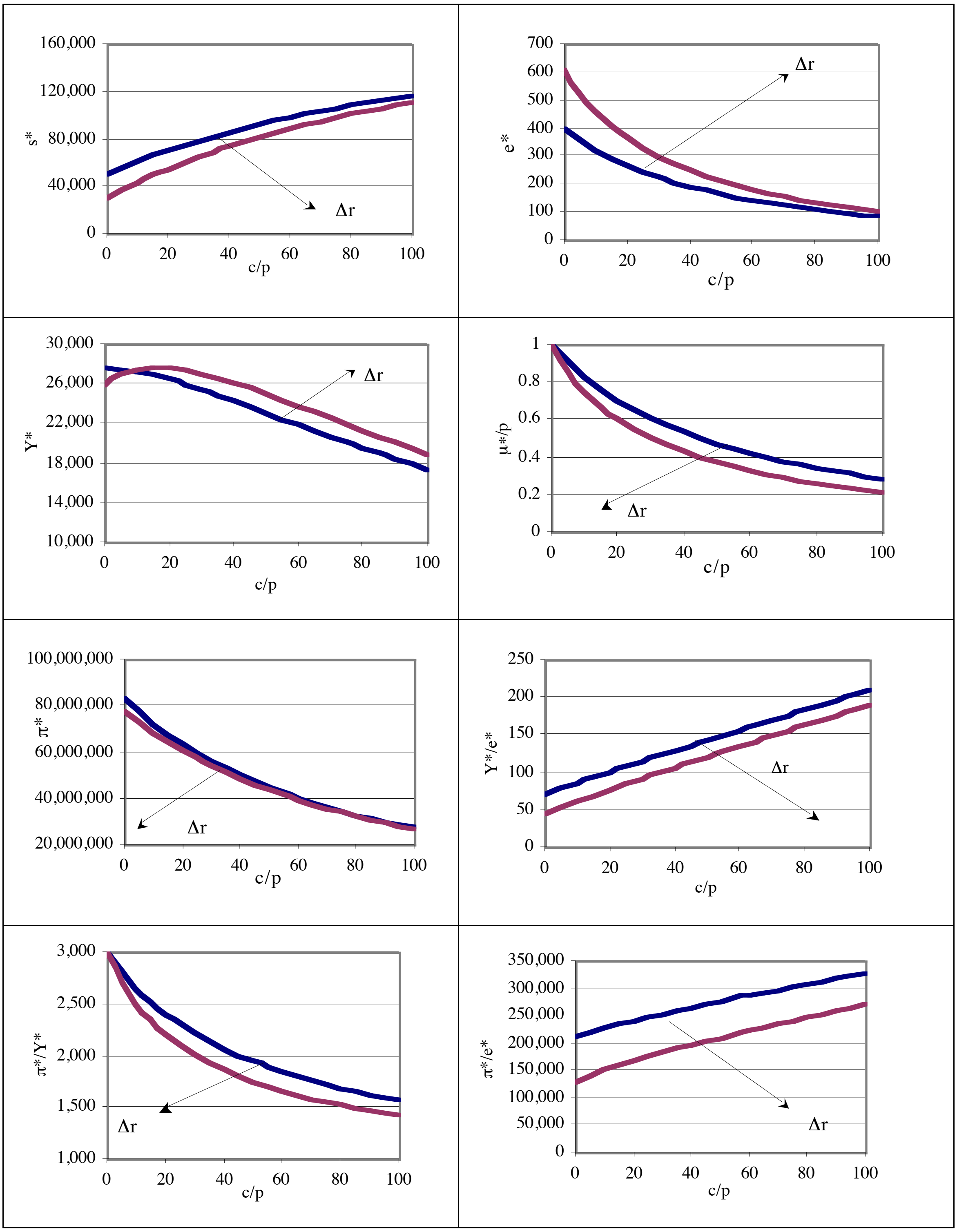
Figure 1 illustrates the sensibility analysis of the optimal allocation (s^*, e^*, Y^*) the social shadow value (μ^*), the maximum profits associated to the fishery (π^*), the average profits per effort unit (π^*/e^*), the average profits per tonne of fish harvested (π^*/Y^*) and the overall average productivity of fishing effort (Y^*/e^*).

Increases in the ratio c/p made less attractive fishing activity. Consequently, $(\Delta c/p)$ has a positive effect on stock (Δs^*) bringing about, via the marginal stock effect, the substitution of factor effort by stock, such that steady state stock grows at a decreasing rate as long as c/p does so, while effort decreases (∇e^*). Although, both, catches and profits fall $(\nabla Y^*$[15]$, \nabla \pi^*)$, notice that the average productivity of effort $(\Delta Y^*/e^*)$ and the profits per unit effort $(\Delta \pi^*/e^*)$ increase. Quite the contrary, raises in the discount rate (Δr) are shown like improvements in profitability from fishing, pushing the fishermen to substitute stock by effort $(\Delta e^*, \nabla s^*)$, resulting in higher catch

[15] Except for low values of c/p and r>0. With sufficiently low values of c/p, optimal stock is below that associated with MSY, steady state catch levels, therefore, increase as far as MSY only to decrease as values of c/p increase.

levels *(ΔY*)*[16]. However, the average productivity of effort and the profits per unit effort decrease *(∇Y*/e*, ∇π*/e*)*.

-Figure 1-
Sensibility analysis of the efficient allocation



[16] The extinction of resources is not optimal for reasonable discount levels. r> 500% for s*=0.

Let's now consider the introduction of corrective taxes on catches *(τ)* or on effort *(γ)*[17] in order to conduct the fishery towards optimality. Taxes on catches reduce net prices obtainable from fish, whereas taxing effort increases its operating costs, both bringing the reduction of the profitability of the fishing activity, which induces some fishermen to abandon it *(∇e)*. The lower pressure on stock originates *Δs* making possible increases in overall profits, partially or totally extracted by the taxing authority. That is way two alternative scenarios have been included: the short run one implying positive after tax net profits (i.e. τ (equations 6) and γ (equation 8)) and the long run open access scenario characterised by zero net profits (i.e. $\tau(\pi=0)$ (equation 9) and $\gamma(\pi=0)$ (equation 10) and maximum tax collection. Table 2 summarises the mentioned different optimal corrective pigouvian taxes for the BC and BI associated to the anchovy fishery. Since firms are assumed to be identical, then $\lambda_i=\mu/N$ for all i.

-Table 2-
Corrective pigouvian optimal taxes on catches (€ per Tm) and on effort (€ per vessel)

	τ	γ	$\tau(\pi=0)$	$\gamma(\pi=0)$
BASE CASE†	[979 - 1,049]	[101,847-113,038]	[1,655 - 1,702]	[258,443 -275,320]
BASE INTERVAL††	[716 - 1,503]	[94,140 - 120,558]	[740 - 2,004]	[111,582 - 307,715]

† BC={c/p=70 ∧ r∈ [0.05, 0.1]} †† BI= {c/p∈[40, 100] ∧ r∈[0.05, 0.1]}. Reference prices, p=[1,500, 3000]

To help undertaking the sensitivity analysis of taxes, Figure 2 illustrates alternative optimal pigouvian taxes for different c/p and r. For concordance with Figure 1, taxes relative to anchovy prices are considered (i.e. τ/p, γ/p, $\tau(\pi=0)/p$, $\gamma(\pi=0)/p$). Notice also that when applying the general formulations in equations (6, 8, 9 and 10) for

[17] Since effort is represented by the number of operating vessels, γ is in fact equivalent to the optimal price of a fishing licence.

a *Cobb Douglas* technology[18] the following equalities and equivalencies hold: a)$\gamma/p=\beta\cdot(Y/e)\cdot\tau/p$; b)$\tau(\pi=0)/p=1-\beta\cdot(1-\tau/p)$; c)$\gamma(\pi=0)/p =(Y/e)\cdot\tau(\pi=0/p)$; d) $\gamma(\pi=0)/p =(Y/e)\cdot(1-\beta) + \gamma/p$.

Both, $\tau(\pi=0)/p$ and τ/p, decrease as the ratio *c/p* and/or *r* increases. Given that ($\Delta c/p \Rightarrow \nabla\mu/p$) and ($\Delta r\Rightarrow\nabla\mu/p$), then: $\{\partial\tau(\pi=0)/p/\partial(c/p)<0; \partial\tau/p/\partial(c/p)<0; \partial\tau(\pi=0)/p /\partial r<0; \partial\tau/p /\partial r<0\}$. Besides, since $\mu/p\leq 1$ *and* $0<\beta<1$, $\tau/p(\pi=0) > \tau/p$ holds. However, $\gamma(\pi=0)/p$ and γ/p, as well as depending on μ/p, also depend on the average productivity of fishing effort *(Y/e)*. Consequently, increases in the ratio *c/p* drive two opposite-signed effects: *1.* $\nabla\mu/p$ *and 2.* $\Delta(Y/e)$. In view of (9) and (10) $\{\partial(\gamma(\pi=0)/p)/\partial(c/p) > 0] \ \forall\ c/p \in[0,100]\}$, while γ/p reaches a maximum value when $c/p =20$ and is decreasing for $c/p>20$[19]. For another side, given that the two effects generated by raises in the discount rate act in the same direction (i.e. 1. $\nabla\mu/p$ and 2. $\nabla(Y/e)$), then $\{\partial\gamma/p(\pi=0)/ \partial r < 0$ and $\partial(\gamma/p)/ \partial r < 0\}$. Moreover, as $0<\beta<1$, *then* $\gamma/p(\pi=0) > \gamma/p$ holds.

The asymmetric nature of taxes on catches and catches on effort due to $\Delta c/p$ needs further explanation. In the case of taxes on effort, the reduction of the profitability associated with $\Delta c/p$ induces some fishermen to abandon the activity *(*∇e*)*, originating *(*Δs*)* and therefore average productivity *(*$\Delta Y/e$*)* and per vessel profit *(*$\Delta\pi/e$*)* increases. Given that the remaining vessels are able to get an increasing average profit despite $\Delta c/p$, the optimal prices of the licences are necessary positively related to $\Delta c/p$. However, when taxing catches, $\Delta c/p$ carries a reduction on the profit per tonne harvested. That is why fishermen would have to pay smaller taxes per tonne fish as a result of $\Delta c/p$.

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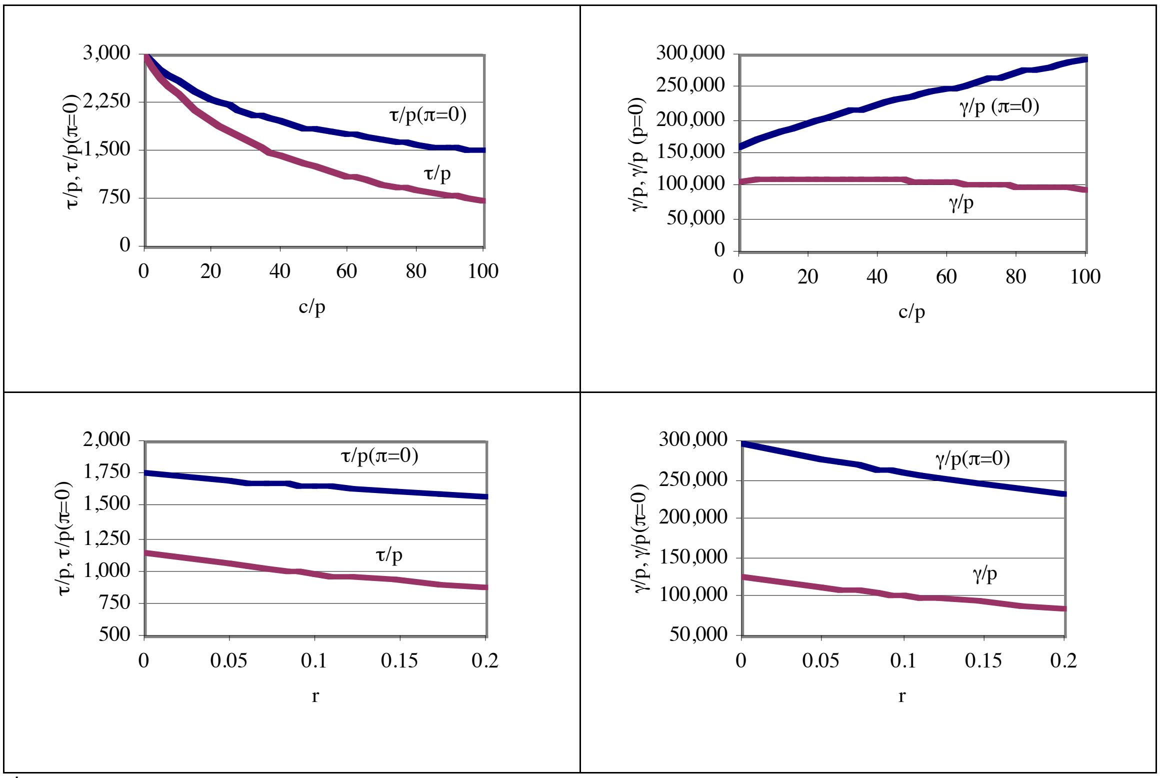
[18] The average productivity of fishing effort (Y/e) equals to β per the marginal productivity of effort. (βf_e) Since $0<\beta<1 \Rightarrow (Y/e) > f_e$

[19] Note that in the case of $\tau/p(\pi=0)$ when $\Delta c/p$ the positive effect of increasing average productivity appears twice, mitigating the negative one $\{\uparrow (Y/e)\ (1-\beta) + \beta(Y/e)\uparrow\mu/p\downarrow\}$ while in the case of γ/p, the increase in the average productivity is compensated with the decrease of the shadow price $\{\beta(Y/e)\uparrow\mu/p\downarrow\}$

- Figure 2 -
Sensibility analysis of optimal taxes[†]



[†] Reference values: r=0.1, c/p =70

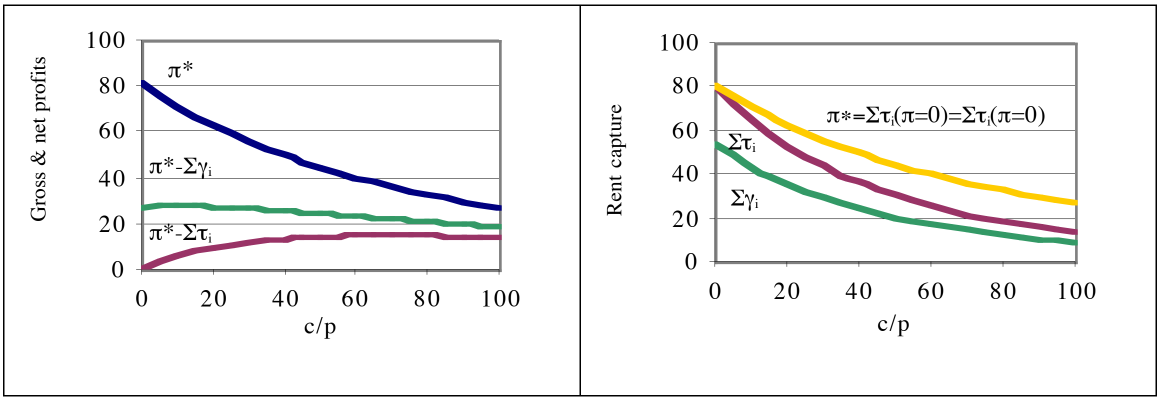
The explicit relationship between catch and effort involves that effort taxes are certainly merely transformations of catch taxes. However, even though both mechanisms are constructed to allow the optimal steady state long run allocation *(s*, e*, Y*)* they present two important peculiarities. For one side, taxing catches or taxing fishing effort has different distributional effects referring to net after tax profits obtainable in the anchovy fishery (see Table 3 and related Figure 3). Particularly, under an effort taxing system, the after tax net profits are higher (and consequently the rent capture smaller) than under a harvest taxing system. For another side, vessels seem to be much more easily gauged than is harvest. Consequently, in our case study effort taxes (i.e on vessels) would normally be expected to provide more accurate control over the fishery than taxes on harvest. However, the fact that fishing effort should be understood to be a composite index of different production factors would imply identifying and taxing all of its components. Otherwise inefficient input substitutions could be propitiated.

-Table 3-
Aggregate gross profits and rent capture under alternative taxing systems (€)

	π^*	$\Sigma\tau$	$\Sigma\gamma$	$\Sigma\tau(\pi=0)$	$\Sigma\gamma(\pi=0)$
BASE CASE†	35.973.030	21.227.543	14.129.477.52	35.973.030	35.973.030

† c/p = 70; r=0,1; p=3000

-Figure 3-
Profits and rent capture under alternative taxing systems (million €)



† r=0,1; p=3000

3. MAIN CONCLUSIONS AND ECONOMIC POLICY RECOMENDATIONS

We have shown the way pigouvian taxes would theoretically correct the misallocation of resources in fisheries (i.e. excessive fishing effort and catch levels) resulting from the stock externality. Moreover, setting the *optimal tax*, either on the output (i.e. harvests) $[\tau_i=\mu-\lambda_i]$ or on inputs (i.e. fishing effort) $[\gamma_i=(\mu-\lambda_i)\cdot f e_i]$, incentives each of the individual fishermen to act as if their respective individual shadow values (λ_i) were equal to the social one (μ). Therefore, the fishery would reach its efficient (i.e. profit maximising) allocation. Regarding the equilibrium profits level, two alternative scenarios had been assumed: the short run one implying positive after tax profits (*π*>0*) and the long run open access zero net profits one (*π*=0*).

With a bio-economic diagnosis characterised by being a long way from optimality, the applied empirical case study developed is the VIII division European anchovy fishery. Accepting the base-case reference cost, price and discount rate values and the estimated parameters for the Cushing growth population function and the Cobb Douglas production function in del Valle et al (2001), a representative fisherman should have to pay about τ=1.000 € per tonne caught, or equivalently about γ=100.000 € per operating vessel, in order to get the maximum aggregate profits from the fishery. The long run open access (i.e. implying zero net profits) pigouvian tax per tonne caught would be of about $\tau(\pi=0)$=1.700 € or equivalently $\gamma(\pi=0)$=160.000 € per operating vessel. Of course $\tau(\pi=0) > \tau$ and $\gamma(\pi=0) > \gamma$ holds.

Bearing in mind that taxes should be continuously adjusted to changing cost price ratios *(c/p)* or even to discount rates *(r)* the sensibility analysis is useful. Optimal tax rates on catches (i.e. $\tau(\pi=0)/p$ and τ/p) are negatively related to μ/p. Thus, it is straightforward that both decrease with c/p or r increases. Optimal taxes on fishing effort (i.e. $\gamma(\pi=0)/p$ and γ/p) as well as depending on μ/p, are also related to the marginal productivity of fishing effort (fe_i). The later increases as c/p does and falls when r rises. Accordingly, the responses to c/p changes of the optimal tax rates on effort and the optimal tax rates on catches are opposite signed. In other words, fishermen would have to pay higher taxes per vessels but smaller taxes per tonne fish as a result of $\Delta c/p$. Notice that $\Delta c/p$ induces increases of the profits per effort unit, but it carries falls on the profit per tonne harvested.

Moreover, accepting the estimated realistic base interval adopted for the sensibility analysis, taxing catches or taxing fishing effort would have different distributional effects. The rent capture would be higher (i.e. the net profits for the fishermen smaller) under the first regime. For another side, at least apparently, vessels seem to be much more easily gauged than catches. Thus, in concordance of having accepted the number of vessels to represent fishing effort, taxes on effort (i.e. on the vessel itself) would be expected to provide more accurate control over the fishery. However, in the real fisheries word, fishing effort is a composite index of different production factors. Consequently, taxing effort would imply taxing all of its components. If not, inefficient input substitution could be induced.

Despite their theoretical properties, taxes have not been the regulatory instrument of choice in real fisheries. For one side, taxing requires huge data needs. For another side, the government should face the political cost of the instrument. Taxation does not benefit fishers, who have political clout in lobbying against taxation, especially if tax rates are positively correlated to the size of the enterprises. However, the development of individual transferable quota (ITQ) fisheries all over the word, has rekindled interest in the idea of imposing special taxes on that sector, following the main objective of transferring wealth from owners of quota to the government in order to partially finance the cost associated to the management system.

The main argument in favour to ITQs is that it eliminates the race for the fish, which presumably would induce the fishermen to adopt cost minimising input configurations. Moreover, transferability allows that rights would be consolidated in the hands of the most efficient operators. Therefore, economic rent emerges, which can either be taxed away by the government or left in the fishery to be capitalised into the value of the quotas. Certainly, as taxes and allocated transferable vessel quotas are mathematically equivalent (i.e. the optimal tax equals the equilibrium market value of the quotas) the economic optimum can be achieved via any combination of taxes and allocated quotas: the market price of the quotas would be simply reduced by the tax.

The adoption of combined ITQ/taxing systems to be applied to anchovy fishery would require important institutional changes and four main work packages. 1) Political decision and acceptance by the sector; 2) The initial allocation (i.e. TAC distribution to the States, quota distribution to individual fishermen, allocation method and criteria); 3) The characteristics of the quotas (prices, temporal horizon, legal status, transferability conditions); 4) Monitoring system (method design, who controls, who pays, sanctioning criteria). Despite there seems to be little prospect of acceptation by the sector, assume it's overcome. The large number of landing ports and the small market distribution chain could be a serious problem to undertake the monitoring system. Besides, potential changes in the fleet structure should be considered, which could drive to negative distributional effects on locally fishing dependent communities.

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APPENDIX 1

a) The *sole owner's* problem

$$\begin{aligned} &\underset{\forall\{e_i(t)\}}{Max} \sum_i \int_0^\infty \left[p \cdot Y(e_i(t), s(t)) - C(e_i(t)\right] \cdot e^{-rt} dt \\ &\qquad st. \quad \dot{s} = G(s(t)) - \sum_i Y(e_i(t), s(t)) \\ &\qquad\qquad s(t), e_i(t) \geq 0, \ \forall i \end{aligned} \tag{I}$$

The current value Hamiltonian function associated to (I),

$$H = \sum_i \left[Y(e_i(t), s(t)) - C(e_i(t)\right] + \mu(t) \cdot \left[G(s(t)) - \sum_i Y(e_i(t), s(t))\right]$$

The maximum and movement equations or necessary conditions for a solution to (I):

$$\frac{\partial H}{\partial e_i(t)} = 0 \Rightarrow \left[p - \mu(t)\right] \cdot Y_{e_i} = C_{e_i}, \quad for \ \forall \ t, i / e_i > 0$$

$$\dot{\mu} = -\frac{\partial H}{\partial s} \Rightarrow \dot{\mu} = \mu(t) \cdot \left(\sum_i Y_s + r - G'(s)\right) - p \cdot \sum_i Y_s$$

$$In\ \ equilibria\ (\dot{\mu}=0) \Rightarrow \mu = \frac{p \cdot \sum_i Y_s}{\sum_i Y_s + r - G'(s)}$$

b) The *private problem*

$$\begin{aligned} &\underset{\{e_i(t)\}}{Max} \int_0^\infty \left[p \cdot Y(e_i(t), s(t)) - C(e_i(t)\right] \cdot e^{-rt} dt \\ &\qquad st. \quad \dot{s} = G(s(t)) - \sum_i Y(e_i(t), s(t)) \\ &\qquad\qquad s(t), e_i(t) \geq 0 \\ &\qquad\qquad e_j, j \neq i\ given \end{aligned} \tag{II}$$

The current value Hamiltonian function associated to (II),

$$H_i = \left[p \cdot Y(e_i(t), s(t)) - C(e_i(t)\right] + \lambda_i(t) \cdot \left[G(s(t)) - \sum_i Y(e_i(t), s(t))\right]$$

The maximum and movement equations or necessary conditions for a solution to (II):

$$\frac{\partial H}{\partial e_i(t)} = 0 \Rightarrow \left[p - \lambda_i(t)\right] \cdot Y_{e_i} = C_{e_i}, \quad for\ \forall\ t, i \,/\, e_i > 0$$

$$\dot{\lambda}_i = -\frac{\partial H}{\partial s} \Rightarrow \dot{\lambda}_i = \lambda_i \cdot \left(\sum_i Y_s + r - G'(s)\right) - p \cdot Y_s, \quad for\ \forall\ i$$

$$In\ \ equilibria\ (\dot{\lambda}=0) \Rightarrow \lambda_i = \frac{p \cdot Y_s}{\sum_i Y_s + r - G'(s)}$$

c) The private problem under *Pigouvian taxes on outputs (catches)*

$$\begin{aligned} &\underset{\{e(i)\}}{Max} \int_0^\infty [(p - \tau_i) \cdot Y(e_i(t), s(t)) - C(e_i(t)] \cdot e^{-rt} dt \\ &\qquad st. \quad \dot{s} = G(s(t)) - \sum_i Y(e_i(t), s(t)) \\ &\qquad\qquad s(t), e_i(t) \geq 0 \\ &\qquad\qquad e_j, j \neq i\ given \end{aligned} \tag{III}$$

The current value Hamiltonian function associated to (III),

$$H = [(p - \tau_i) \cdot Y(e_i(t), s(t)) - C(e_i(t)] + \lambda_i \cdot [G(x) - \sum_i Y(e_i(t), s)]$$

$$\frac{\partial H}{\partial e_i(t)} = 0 \Rightarrow [p - \lambda_i - \tau_i] \cdot Y_{e_i} = C_{e_i}, \quad for\ \forall\ t, i \,/\, e_i > 0$$

$$\dot{\lambda}_i = -\frac{\partial H}{\partial s} \Rightarrow \dot{\lambda}_i = \lambda_i \cdot (\sum_i Y_x + r - G'(s)) - (p - \tau_i) \cdot Y_x$$

Comparing the maximum equation associated to problem I and III the optimal tax per unit of catches that allows the equilibrium optimal allocation will be $\tau_i = \mu - \lambda_i$,

$$\tau_i = \frac{p\cdot \sum_i Y_s - p\cdot Y_s}{\sum_i Y_s + r - G'(s)}$$

c) The private problem under *Pigouvian taxes on inputs (effort)*

$$\underset{\{e(i)\}}{Max}\int_0^\infty [p\cdot Y(e(i),x) - \gamma(i)\cdot e(i) - C(e(i)]\cdot e^{-rt}dt \qquad \text{(IV)}$$

$$st. \quad \dot{x} = G(x) - \sum_i Y(e(i),x;i)$$

$$x, e(i), \tau(i) \geq 0, \quad \forall i$$

$$H = [p\cdot Y(e_i(t),s(t)) - \gamma_i\cdot e_i - C(e_i(t)] + \lambda_i\cdot[G(x) - \sum_i Y(e_i(t),s)]$$

$$\frac{\partial H}{\partial e_i(t)} = 0 \Rightarrow [p-\lambda_i]\cdot Y_{e_i} = \gamma(i) + C_{e_i}, \quad for\ \forall\ t,i\,/\,e_i > 0$$

$$\dot{\lambda}_i = -\frac{\partial H}{\partial s} \Rightarrow \dot{\lambda}_i = \lambda_i\cdot(\sum_i Y_s + r - G'(s)) - p\cdot Y_s$$

Comparing the maximum equation associated to problem I and IV, it is straightforward

that $\gamma_i = [\mu - \lambda_i]\cdot Y_{e_i}$

$$\gamma_i = \left[\frac{p\cdot \sum_i Y_s - p\cdot Y_s}{\sum_i Y_s + r - G'(s)}\right]\cdot Y_{e_i}$$

APPENDIX 2

a) Table I: *The population growth function*

Cushing population growth function† *ln(s(t+1)+Y(t)) = lna+bLn(t)⇒ g(s(t)=72.2549s(t)*$^{0.645}$*-s(t)* †						
lna = 4.28** (7.69)	b= 0.645** (6,82)	*F* 46.55	$\overline{R}^2$ 0.61	D. Watson 2.10	Box Pierce††† 7.46	Jarque Bera 0.83

Source (del Valle et al. (2001)
** Significant at 5%
† Estimation method: OLS
†† Implies a maximum sustainable yield MSY= 27,571.7 tonnes, a required biomass for MSY of 50,095 and a maximum carrying capacity (MCC) of172,479 tonnes.

b) Table 2: *The production function*†

Cobb Douglas production function *lnY(t) = lnq +* α *Lns(t) +* β *Lne(t)* ⇒ *f(s(t),e(t))=0.319915s(t)*$^{0.68226}$*e(t)*$^{0.668226}$*]*							
lq = -1.1397 (-0.9265)	α=0.68226** (7.11)	β=0.6656** (3.12)	*F* 52.68	$\overline{R}^2$ 0.78	D. Watson 1.91	Box Pierce 12.22	Jarque Bera 2.28

Source (del Valle et al. (2001)
†† Estimation method: OLS
** Significant at 5%