The distributional impact of common-pool resource regulations*

Stefan Ambec† and Carine Sebi‡

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Abstract

Regulating common-pool resources is welfare enhancing for society but not necessarily for all users who therefore may oppose regulations. We examine the short-term impact of common-pool resource regulations on welfare distribution. Market-based regulations such as fees and subsidies or tradable quotas achieve a higher reduction of extraction from free-access than individual quotas with the same proportion of better-off users. They make also more users better-off for the same resource preservation. The quota regulation has attractive fairness properties: it reduces inequality while still rewarding the more efficient users.

Key Words: common-pool natural resources, regulation, quota, welfare, fairness, fishery.

JEL classification: H23, Q22, Q28.

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†Toulouse School of Economics (INRA-LERNA) and University of Gothenburg. Address: 21 Allée de Brienne, 31000 Toulouse, France. Phone: +33 5 61 12 85 16. Fax: +33 5 61 12 85 20. stefan.ambec@toulouse.inra.fr

‡GAEL, University of Grenoble, France. E-mail: carine.sebi@grenoble.inra.fr

1 Introduction

Since at least Gordon (1954) and Hardin (1968), it has been well known that the open access extraction of natural resources (e.g. clean air, water, fish, forests) leads to over-exploitation. Efficiency can be improved under regulated extraction. Consistently, natural resource extractions have been extensively regulated worldwide. For instance, in the fishing industry, several regulatory tools have been implemented to reduce over-fishing, including access rights, vessel buy-backs, quotas and fishing restrictions. Such regulations have heterogeneous impacts on the fishermen's welfare. Although some might improve their situation compared to open access, others might lose out and therefore strongly oppose regulations. Despite being welfare-improving for the fishing industry as a whole, regulations might encounter strong opposition and thus be difficult to implement. The political feasibility of new fishing regulations should take into account their acceptability by the fishing industry, on the basis of individual welfare.

This paper examines the distributional impact of regulatory instruments that reduce resource extraction. How far can the regulation go in reducing resource extraction under the constraint of Pareto-improvement from free-access in the short run? How many users will lose from free-access if the regulation reduces extraction further? Which regulation obtain more political support? Which one is perceived as fair by users? According to which fairness principles?

We focus on three regulatory instruments. The first one is an access fee to the resource and a subsidy for those who stop extraction. This is referred to as the fee and subsidy (FS) scheme. It must be budget-balanced: the subsidies must be entirely financed by the fees collected.[1] The second instrument is an individual, uniform and non-transferable quota (IQ). It imposes restrictions or quotas on inputs (e.g. fishing days, net or vessel size) or output (e.g. catch). The third instrument allows the users to exchange their quotas (on input or output) in a competitive market. It is referred to as the individual transferable quota (ITQ) scheme.

The FS, IQ and ITQ regulations are commonly used to regulate fisheries. For instance, in the Bering Sea, National Marine Services implemented crab fishery boat buy-backs and

[1] Note that in our framework an access fee is equivalent to a tax on output (e.g. catch) in equilibrium.

landing fees to reduce the crab decline. The buy-backs were financed by a loan to be repaid over 30 years by catch landing fees of crab fishermen who remained in the fishery. There are different types of quota. Input restrictions such as vessel size, maximal season length, net size and fishing techniques are individual and non-transferable quotas on inputs. Individual and non-transferable quotas on outputs are also applied. For instance, the United Kingdom divides its allowable catch as fixed by the European Union among groups of fishermen through individual quotas on catches. Individual and transferable quotas are more and more popular worldwide, especially in New Zealand, Australia, Canada and the United States.[2]

To assess the acceptability of the above regulations in a simple model, we employ the following modelling strategy. First, since we focus on the short-term impact of regulations, we rely on a static model of common resource extraction à la Gordon (Gordon 1954), thereby abstracting for dynamic considerations such as the evolution of the resource stock. Over-extraction is inefficient in the short run (e.g. the current fishing season) because it reduces the return of user's investment in the extraction effort.[3] Second, to capture the efficiency gain of market-based regulations (FS and ITQs) and to be able to analyze inequality, we need some heterogeneity in the user population, e.g., among fishermen. We therefore introduce a heterogeneous but constant marginal extraction cost.[4] As with homogenous cost, under free access, fishermen extract the resource provided their profit is positive. With heterogenous costs only the fisherman with highest cost makes no gain from fishing; all others obtain a strictly positive profit. Out of the fear of losing this profit, they might therefore be reluctant to agree to regulations.

We first examine how far the regulation can go in reducing total fishing effort under the constraint of Pareto improvement from free-access. We provide necessary and sufficient conditions for the implementation of a targeted fishing effort under Pareto-improvement constraint. In our framework, FS and ITQs are equivalent since they yield the same outcome

[2]Documented examples can be found in Bjorndal and Munro, 1998, or Hannesson, 2004).

[3]In a static framework, free access extraction leads to inefficient extraction because the return of one extraction effort for a fisherman is the average product (and *not* the marginal product) which is equalized to marginal cost in equilibrium with a continuum of fishermen as assumed here.

[4]Marginal costs are private information which rules out heterogeneous regulations such as quotas or taxes contingent on marginal costs.

in equilibrium. These conditions imply that the two market-based instruments (FS and ITQs) implement at least the same fishing effort than IQs but can reduce it further. When the fishing effort is reduced further such that the Pareto-improvement constraint is violated, more fishermen are better-off under FS and ITQs than under IQs. Furthermore, a higher fishing reduction can be achieved under FS and ITQs under the constraint that a given proportion of fishermen or better-off than under free-access.

Although market-based instruments dominate IQs regarding efficiency and individual welfare improvement, they have two fairness drawbacks. First, by paying the same subsidy to all fishermen, they do not reward those who previously invested to improve their fishing technology and skills. Second, they preserve the same differences in welfare among those who still fish under regulation. By contrast, IQs both reward more efficient fishermen for their past investments and reduce inequality among fishermen. These two fairness properties might make non-tradable quotas attractive to reduce common-pool resource extraction despite their underperformance in improving individual and total welfare.

This paper is related to the theoretical literature on common-pool resource extraction. Most of this literature focuses on the emergence and enforcement of endogenous extraction rules. Users play a common-pool resource game in which they might voluntarily refrain from extraction and possibly even punish those who do not do likewise (Ostrom 1990, Sethi and Sommanathan, 1996, Dayton-Johnson and Bardhan, 2002, Baland and Platteau, 2003).[5] In contrast, here we consider exogenous regulations imposed on users. We examine the voluntary adherence to those rules by selfish users who fully comply with them. In particular, we investigate how far the regulator can go in reducing extraction without hurting them.

Several papers have examined the welfare and distributional impact of a specific regulation of a common resource, namely privatization. Privatization improves total welfare but might reduce individual welfare because users earn the marginal product rather than the average product (Weitzman, 1974, De Meza and Gould, 1987) or are exposed to more risk (Baland and Francois, 2005).[6] Here we focus on other regulations which also improve

[5] In the same vein, Burton (2003) studies the problem of rule enforcement and explores how sanctions affect heterogeneous fishermen within a community, using limited entry and uniform quotas.

[6] In contrast, Ambec and Hotte (2006) argue that users deprived of their common property rights might benefit from privatization by extracting the resource illegally.

total welfare but have non-trivial impacts on individual welfare. Those regulations do not exclude some users but rather regulate their activity.

In the economics of fisheries, several papers compare fishery regulations but with a different focus. Androkovich and Stollery (1991) and Weitzman (2002) consider homogeneous fishermen who face uncertainty in estimating the fish stock size and the demand for fish. They argue that price-based instruments such as landing fees are more efficient than quantity-based ones such as individual quotas. With deterministic fish stock and demand but with heterogenous fishermen, as assumed here, those two regulations lead to the same equilibrium outcome as long as quotas are transferable. Johnson and Libecap (1982) discuss how heterogeneity in fish skills affects regulation acceptability. They highlight the fact that *"without side payments (...), uniform quotas could leave more productive fishermen worse off than under common property conditions"*. Consistently, in our model the more efficient fishermen are those who experience the lowest welfare improvement under IQs and therefore bind the "political feasibility constraint". Johnson and Libecap also suggest that egalitarian pressure favours uniform quotas. We rationalize this claim by showing than IQs reduce inequalities while ITQs exacerbate them.[7]

The paper is organized as follows. After presenting the model and free access regime in Section 2, we consider successively the three regulatory instruments: the fee and subsidy scheme (Section 3), non-transferable quotas (Section 4) and transferable quotas (Section 5). We compare the three instruments in Section 6. Section 7 concludes the paper.

2 The model

The model is borrowed from Ambec and Hotte (2006). A community of individuals are extracting a natural resource from a common pool. Typical examples of such common-pool natural resources include fisheries, forests for timber or fuel-wood, hunting grounds and pastures. For the sake of simplicity, the common-pool resource will be called the "fishery"

[7] In the same strand of literature, Clark, Munro and Sumaila (2005) study the impact of buy-back subsidies on fisheries previously extracted under open-access in a dynamic framework. They highlight the fact that fishermen's anticipation of future buy-backs might lead to overcapacity. They suggest the implementation of "incentive-adjusting approaches to management". We assume here that fishermen do not anticipate the buy-back regulation, which avoids the overcapacity problem.

and the extractors the "fishermen", although the model is applicable to other common-pool resources.

Each fisherman selects a fishing effort x. For every fishing effort, a fisherman obtains the average product of extraction $\phi(X)$ where X is the total fishing effort. The average product is assumed to be decreasing in the fishing effort, i.e., $\phi' < 0$. Total production is denoted $F(X)$ and defined by $F(X) = \phi(X)X$. Fishermen are endowed with the same effort capacity $\bar{x}$ but differ by their fishing cost. They are labelled according to their constant marginal cost of fishing c which is private information. The fishing cost includes wages, the annual cost of a vessel, fuel, and the price of other inputs. It might also include the opportunity cost of spending this time and money in fishing. Moreover, heterogeneous fishing costs might capture differences in fishing skills since to obtain the same "fishing effort" some fishermen might need to spend more inputs (e.g. time in the fishery). There is a continuum of fishermen (of mass 1) with costs $c \in [\underline{c}, \bar{c}]$ (with $0 < \underline{c} < \bar{c}$) distributed according to the cumulative $G(c)$ and density $g(c)$. The price of the resource is normalized to 1. When investing x units of fishing effort, the fisherman c obtains $\pi(c) = x(\phi(X) - c)$ from the fishery.[8]

We first consider the benchmark free-access (FA) extraction framework. In our set-up, it is easy to show that, under free access, there exists a threshold cost c^{FA} such that fishermen with lower costs fish up to their capacity $\bar{x}$ while the others do not fish at all. For a given equilibrium fishing effort X^{FA}, a fisherman obtains the average product $\phi(X^{FA})$ per unit of effort. He fishes so long as his benefit exceeds his marginal cost c. Denote c^{FA} the fisherman whose marginal cost equals the free-access average product, i.e,

$$c^{FA} = \phi(X^{FA}). \tag{1}$$

All fishermen with c lower than c^{FA} obtain more than their marginal cost per unit of effort. They fish up to their capacity $\bar{x}$. Fishermen whose cost is higher than c^{FA} lose out for each unit of effort. They do not fish. The total fishing effort under FA is thus:

$$X^{FA} = \int_{\underline{c}}^{c^{FA}} \bar{x} dG(c) = \bar{x}G(c^{FA}). \tag{2}$$

[8]If c includes only opportunity costs, the fisherman's payoff on fishing is $x\Phi(X)$, and the remaining units $\overline{x} - x$ are invested in an outside activity which yields $(\overline{x} - x)c$ to fishermen c.

Figure 1 below illustrates the FA equilibrium

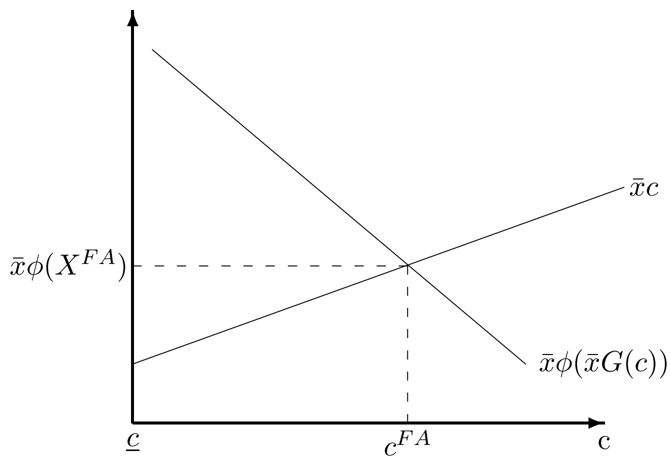


Figure 1. *Extraction under free access*

The downward sloping curve $\bar{x}\phi(\bar{x}G(c))$ represents the benefit from fishing $\bar{x}$ units of effort when fishermen with costs up to c fish at their maximal capacity. The upward sloping curve is the total costs of the fisherman c when exerting effort $\bar{x}$. The threshold fisherman under FA c^{FA} makes zero profit from fishing (see condition (1)), meaning that his benefit $\bar{x}\phi(X^{FA})$ is equal to his cost of fishing $\bar{x}c^{FA}$. It is therefore defined where the above two lines cross. Each fisherman $c < c^{FA}$ makes a strictly positive profit equal to the distance between his benefit at the equilibrium $\bar{x}\phi(X^{FA})$ (the dotted line) and his total cost $\bar{x}c$ on the upward sloping curve. Fisherman c's profit under open-access for every $c \leq c^{FA}$ is thus:

$$\pi^{FA}(c) = \bar{x}[\phi(X^{FA}) - c]. \tag{3}$$

The FA regime is inefficient because fishermen extract the resource until the marginal cost is equal to the average product instead of the marginal product. This is the well-known over-exploitation result of open access extraction of natural resources. Fishing effort must be reduced to restore or, at least, increase efficiency. This is indeed the goal of regulations.

In the next three sections we examine the performance of regulations in implementing a targeted fishing effort $\tilde{X} < X^{FA}$ under political feasibility constraints. One of the targeted fishing effort could be the one that maximizes the fishing industry's welfare in the short run (i.e. for a given stock). Let us denote it X^*. Since it is efficient to make fishermen with lowest cost invest all their fishing effort capacity $\bar{x}$, X^* can be found by selecting the threshold fishing cost $\tilde{c}$ that maximizes the total welfare from fishing defined as:

$$F(\bar{x}G(\tilde{c})) - \bar{x}\int_{\underline{c}}^{\tilde{c}} cdG(c) = \int_{\underline{c}}^{\tilde{c}} \bar{x}[\phi(\bar{x}G(\tilde{c})) - c]dG(c). \quad (4)$$

The above left-hand term is total catches net of total costs, which is equal to the sum of profits in the right-hand side. The solution c^* is defined by the following first-order condition:

$$F'(X^*) = \phi'(X^*)X^* + \phi(X^*) = c^*, \quad (5)$$

with $X^* = \bar{x}G(c^*)$. The total welfare from fishing is maximized by letting all fishermen invest their fishing capacity up to the fisherman whose cost c^* equals the marginal product $F'(X^*)$.

Yet it is optimal for society to target a fishing effort below X^* when the common-pool resources exhibits positive externalities stemming from teh stock's size. In particular, the resource might benefit to those who don't extract it. For instance, a high fishing stock might contribute to the marine bio-system to the benefit of other users of it (e.g. bird watchers, sportive fishers, scuba-divers).[9] We thus examine the impact of the implementation of *any* targeting fishing effort with regulations on fishermen's welfare. We consider successively three regulatory instruments: a fee and subsidy scheme (FS) in Section 3, individual quotas (IQs) in Section 4, and individual transferable quotas (ITQs) in Section 5.

3 The fee and subsidy scheme

The first regulatory instrument that we consider is an access fee τ and a subsidy σ for those who agree to quit the fishing industry. Only active fishermen in the free-access regime can apply for the subsidy. It can take the form of boat buy-backs or unemployment and reconversion benefits. Access is also restricted to active fishermen in the FA regime. The fee

[9] In this case a subsidy to the fishing industry might be justified. It relaxes the budget balance constraint of the fee and subsidy scheme and therefore might help to enhance fishermen's profit.

and the subsidy are the same for all fishermen.[10] The FS scheme must be budget balanced in the sense that all subsidies must be entirely financed by the fees collected.

The FS regulation raises the cost of fishing by τ and the benefit from not fishing by σ. Fisherman c's profit with a fishing effort $x > 0$ is thus $x[\phi(X) - c] - \tau$ and σ if $x = 0$. As with under free-access, those fishermen whose cost is lower than a threshold level fish up to their capacity while those with a cost higher cost do not fish. The threshold cost denoted $\tilde{c}$ depends on both τ and σ. It is defined by:

$$\bar{x}[\phi(\tilde{X}) - \tilde{c}] - \tau = \sigma, \tag{6}$$

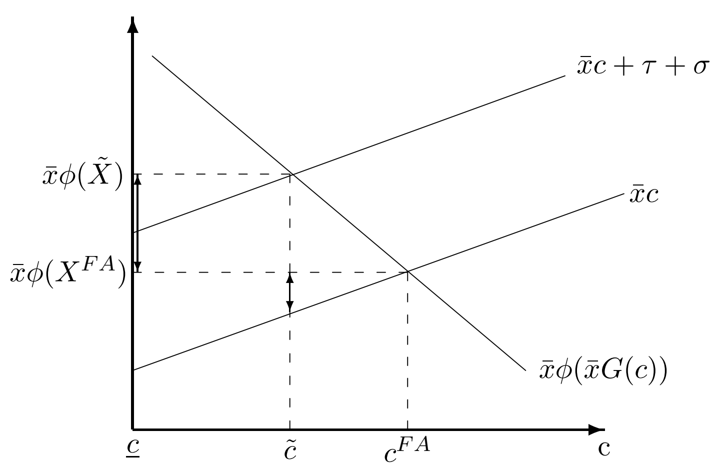
where $\bar{x}G(\tilde{c}) = \tilde{X}$. The threshold fisherman $\tilde{c}$ is indifferent between fishing or not. He obtains the same profit while fishing (left-hand side of (6)) or not fishing (right-hand side of (6)). The total fishing effort obtained under this regulation is:

$$\tilde{X} = \int_{\underline{c}}^{\tilde{c}} \bar{x} dG(c) = \bar{x}G(\tilde{c}). \tag{7}$$

Combining (6) with (7) leads to:

$$\bar{x}[\phi(\bar{x}G(\tilde{c})) - \tilde{c}] - \tau = \sigma. \tag{8}$$

The FS scheme (τ, σ) increases the opportunity cost of fishing by $\tau + \sigma$, as fisherman c has to pay τ but also give up the subsidy σ if he or she fishes. It moves upward the total costs line of $\bar{x}$ units of effort in Figure 2 below.



[10]It would be more efficient to define an access fee and a subsidy contingently on c. However, it is not feasible here because c is private information.

Figure 2. *Extraction with an access fee and subsidy scheme.*

The fisherman $\tilde{c}$ who is indifferent between fishing or not is defined where the new cost curve $\bar{x}c+\tau+\sigma$ crosses the benefit curve $\bar{x}\phi(\bar{x}G(c))$. The fishing effort implemented is $\tilde{X} = \bar{x}G(\tilde{c})$. Each fisherman with $c < \tilde{c}$ fishes and makes a strictly positive profit which is equal to the distance between the equilibrium benefit $\bar{x}\phi(X)$ and his total cost $\bar{x}c + \tau$. Those with $c > \tilde{c}$ obtain the subsidy σ.

The FS scheme (τ, σ) must satisfy the following budget-balanced constraint:

$$\tau G(\tilde{c}) \geq \sigma(G(c^{FA}) - G(\tilde{c})). \tag{9}$$

Combining (6) with the binding budget-balanced constraint (9) leads to:

$$\tau = \bar{x}\left[\phi(\tilde{X}) - \tilde{c}\right]\left(1 - \frac{G(\tilde{c})}{G(c^{FA})}\right), \tag{10}$$

$$\sigma = \bar{x}\left[\phi(\tilde{X}) - \tilde{c}\right]\frac{G(\tilde{c})}{G(c^{FA})}, \tag{11}$$

The incentive constraint (6) forces $\tau + \sigma$ to be equal to the threshold fisherman's profit $\bar{x}\left[\phi(\tilde{X}) - \tilde{c}\right]$. The budget balance constraint divides this profit between the fee τ and the subsidy σ. The share of the fee and subsidy depends on the ratio of remaining fishermen under the new regime $\frac{G(\tilde{c})}{G(c^{FA})}$. A higher reduction of resource extraction leaves less fishermen on the fishery and more outside. Therefore the fee τ must be increased to cover the cost of subsidizing more fishermen from not fishing. Although each remaining fisherman pays more, each of those who give up fishing receives less.[11]

To sum up, a budget-balanced access-fee and subsidy regulation that implements a total fishing effort $\tilde{X}$ yields to each fisherman $c \leq \tilde{c}$ a payoff,

$$\pi^{FS}(c) = \bar{x}[\phi(\tilde{X}) - c] - \bar{x}\left[\phi(\tilde{X}) - \tilde{c}\right]\left(1 - \frac{G(\tilde{c})}{G(c^{FA})}\right) \tag{12}$$

and to each fisherman with $c \geq \tilde{c}$,

$$\pi^{FS}(c) = \bar{x}\left[\phi(\tilde{X}) - \tilde{c}\right]\frac{G(\tilde{c})}{G(c^{FA})}, \tag{13}$$

[11] Note that with extra funds, i.e. if the budget-balancing is relaxed, the same target effort X can be obtained with a lower fee and/or a higher subsidy while $\tau + \sigma$ remaining unchanged to satisfy the incentive constraint.

where threshold fisherman is defined by the unique cost $\tilde{c}$ such that $\bar{x}G(\tilde{c}) = \tilde{X}$.

We now compare these profits with the ones obtained under free access to asses the political feasibility of the FS scheme (τ, σ). Our first criteria is Pareto-improvement: everybody (those who still fish and those who do not fish anymore) must be better off under the regulation than under FA. Formally, the following Pareto-improvement constraint must hold for every $c \leq c^{FA}$:

$$\pi^{FS}(c) = \max\{\bar{x}[\phi(\tilde{X}) - c] - \tau, \sigma\} \geq \pi^{FA}(c). \tag{14}$$

Combining (3), (6), (9), (14), and the definition of total fish harvest $F(X) = \phi(X)X$ lead to:

$$\frac{F(X^{FA}) - F(\tilde{X})}{X^{FA} - \tilde{X}} \leq \tilde{c} \tag{15}$$

A Pareto-improving FS scheme implements any fishing effort level $\tilde{X}$ that satisfies inequality (15) where $\tilde{c}$ is defined in (6). It requires that the loss of total catches (fishing production) per unit of fishing effort reduction does not exceed the cost of the less efficient fisherman under FS. It turns out that (15) is also a sufficient condition for $\tilde{X}$ to be implemented with Pareto-improvement. It is easy to show that if (15) holds then (τ, σ) defined above satisfies conditions (6) and (14).

Many fishing efforts can be implemented with a Pareto-improving FS regulation. It is in particular the case of the fishing effort that maximizes the total welfare from fishing X^* defined in (5). By concavity of $F(X)$, $F(X^*) \geq \frac{F(X^{FA}) - F(X^*)}{X^{FA} - X^*}$ which, combined with (5), leads to

$$\frac{F(X^{FA}) - F(X^*)}{X^{FA} - X^*} \leq c^*,$$

that is condition (15) with $X^* = \tilde{X} = \bar{x}G(\tilde{c})$ and $\tilde{c} = c^*$. Hence, reducing fishing effort to X^* with a fee and subsidy scheme not only maximizes the total welfare from the fishery industry but also improve the welfare of all fishermen.

Yet the regulator may want to reduce fishing effort further when the fishing stock creates a positive externality to society (e.g. due to its bio-diversity value or because it feeds other species). If the target fishing effort $\tilde{X}$ violates (15), such a further reduction in fishing effort makes *all* fishermen under FS be worse-off than under FA. Indeed, $F(X) = \phi(X)X$ and (15) violated implies $\bar{x}[\phi(\tilde{X}) - \tilde{c}] < \bar{x}[\phi(X^{FA}) - c^{FA}]\frac{X^{FA}}{\tilde{X}}$, which, combined with (10), (12) and (3), leads to $\pi^{FS}(\tilde{c}) < \pi^{FA}(\tilde{c})$: fishermen with cost $\tilde{c}$ are worse off under the FS regulation than under FA. Moreover, since $\pi^{FS}(c) - \pi^{FA}(c) = \bar{x}[\phi(\tilde{X}) - \phi(X^{FA})]$ for every $c \leq \tilde{c}$, all fishermen with cost $c \leq \tilde{c}$, who therefore fish under the FS regulation, experience the same welfare loss from the FA regime than fisherman $\tilde{c}$. They are all worse off under the FS regulation than under FA. Only some of fishermen who stop fishing under FS benefit from the regulation. More precisely, the fishermen who benefit from the FS regulation are those who exit the fishery and have cost higher than c^{FS} defined by $\sigma = \pi^{FA}(c^{FS})$, that is:

$$c^{FS} = \frac{F(X^{FA}) - F(\tilde{X})}{X^{FA}} + \frac{\tilde{X}}{X^{FA}}\tilde{c}. \tag{16}$$

We thus established the following result.

Proposition 1 *A reduction of fishing effort with a budget-balanced fee and subsidy scheme to $\tilde{X}$ is Pareto-improving if and only if*

$$\frac{F(X^{FA}) - F(\tilde{X})}{X^{FA} - \tilde{X}} \leq \tilde{c}$$

with $\tilde{c}$ such that $\bar{x}G(\tilde{c}) = \tilde{X}$. For higher fishing effort reductions, only fishermen who exit the fishery and whose cost is higher than c^{FS} benefit from the FS regulation.

Proposition 1 implies that, for a targeting fishing effort that violates (15), all fishermen with $c \leq c^{FS}$ are likely to oppose the FS regulation. Fishermen with $c \geq c^{FS}$ who are the only ones who benefit from the FS regulation and, therefore, might vote in favor. Depending of the fishing effort reduction and the distribution of costs (and thus c^{FS}), they may or may not constitute a majority. If not, a transfer from society to the fishing industry is required to buy political feasibility. By relaxing the budget balance constraint (9), it allows to reduce the access fee τ and to increase the subsidy σ which decreases c^{FS} and, therefore, the proportion of fishermen who benefit from the regulation. Such a transfer can be justified by the positive externality that the fish stock exhibits on society that leads the regulator reduce fishing effort below X^*. It can be implemented by taxing the agents who benefit from the positive externality, i.e. those who benefit from the fishery outside the professional fishing industry.

Notice that we have considered a FS regulation in which access to the fishery is restricted to active fishermen in the FA regime. Agents with cost higher than c^{FA} are not allowed to access the fishery nor to get the subsidy. Yet, since the average return $\phi(\tilde{X})$ is increased from FA, they might be tempted to enter into the fishing industry even though they have to pay the access fee τ. They do not as long as the FS regulation is Pareto-improving. Indeed it is easy to show the increased in average return $\bar{x}[\phi(\tilde{X}) - \phi(X^{FA})]$ is lower than the access fee τ if (15) holds. It is only when active fishermen under FS do not benefit from the regulation that new fishermen with costs $c > c^{FA}$ want to enter in the fishing industry. If they cannot be excluded, the access fee must be increased further to implement the target fishing effort $\tilde{X}$.

Before moving on to quotas, it is worth to mentioning that, in our model, the access fee regulation is equivalent to a tax rate on fishing effort or on catch at the equilibrium. More precisely, the same reduction of the fishing effort with the same individual profit can be obtained with a tax rate $\frac{\tau}{\bar{x}}$ on each unit of input x (e.g. labor, fishing supply, fuel) or a tax $\frac{\tau}{\bar{x}\phi(X)}$ on catch or output $x\phi(X)$ instead of an access fee τ.[12] We now examine an alternative regulatory instrument that reduces fishing efforts: individual quotas.

4 Individual Quotas

Consider first a uniform individual and non-transferable quota (IQ) on fishing efforts. Fishermen are allowed only $\tilde{x}$ units of fishing effort with $\tilde{x} < \bar{x}$. Examples of such regulations include fishing season restrictions, specific equipment or size of vessels. It only applies to fishermen active under FA, i.e. those with $c < c^{FA}$.[13]

The IQ regime has two impacts. First, it restricts entry to fishermen $c \leq c^{FA}$. Second, it reduces the individual effort capacity to $\tilde{x}$. As before, fishermen fish up to their allowed capacity now $\tilde{x}$. The total fishing effort implemented is:

$$\tilde{X} = \int_{\underline{c}}^{c^{FA}} \tilde{x} dG(c) = \tilde{x}G(c^{FA}),$$

[12]This equivalence is mostly due to our assumption of a constant marginal cost which provides incentives to use full effort capacity with per input or per output tax rates once the fisherman has decided to renounce to give up the subsidy. It is also due to the fact that each fisherman takes the average return as given with a continuum of fishermen as assumed here.

[13]If everybody can fish up to the quota, since the average product becomes higher than c^{FA}, then some fishermen with $c > c^{FA}$ who did not fish under free access will fish under the IQ regime. A higher fishing effort reduction can be achieved by assigning quotas only to the active fishermen under FA.

which is obviously lower than under free access. Therefore the average product is higher, i.e., $\phi(\tilde{X}) > \phi(X^{FA})$. Hence, implementing a fishing effort $\tilde{X}$ under IQs requires assigning the following quota level to every fishermen :

$$\tilde{x} = \frac{\tilde{X}}{G(c^{FA})}. \tag{17}$$

The equilibrium profit of a fisherman c is:

$$\pi^{IQ}(c) = \frac{\tilde{X}}{G(c^{FA})}[\phi(\tilde{X}) - c]. \tag{18}$$

As before, we first examine Pareto-improving regulations compared to FA. An individual quota level $\tilde{x}$ improves fisherman c's profit compared to free-access if:

$$\tilde{x}[\phi(\tilde{X}) - c] \geq \bar{x}[\phi(X^{FA}) - c].$$

The above condition must be satisfied for every fisherman $c \leq c^{FA}$. It can be rewritten as,

$$c(\bar{x} - \tilde{x}) \geq \bar{x}\phi(X^{FA}) - \tilde{x}\phi(\tilde{X}), \tag{19}$$

for every $c \leq c^{FA}$. The right-hand term in (19) is the variation of catch or total revenue. Its sign is ambiguous. Although fishermen experience an increase of their catch per unit of effort (i.e. ϕ increases), since the effort level is lower, the total harvest and therefore the total revenue ($\tilde{x}\phi$) might decrease. If revenues increase or remain equal, i.e. if the right-hand term in (19) is positive or nil, then the Pareto-improvement condition holds for all fishermen. If they decrease, i.e. if the right-hand term in (19) is strictly negative, then some fishermen might lose out under the IQ regulation. Since the left-hand side is increasing with c, a necessary and sufficient condition for the Pareto-improvement condition (19) to hold for all fishermen is the fact that it holds for fisherman $\underline{c}$, i.e.,

$$\frac{\phi(X^{FA}) - \underline{c}}{\phi(\tilde{X}) - \underline{c}} \leq \frac{\tilde{x}}{\bar{x}}.$$

Using (2), (17) and $F(X) = \phi(X)X$, one can show that the above inequality is equivalent to

$$\frac{F(X^{FA}) - F(\tilde{X})}{X^{FA} - \tilde{X}} \leq \underline{c}. \tag{20}$$

All fishermen are better-off under individual quotas if the loss of total catches per unit of fishing effort reduction is not higher than the cost of the more efficient fisherman. Condition

(20) is similar to (15) by its left-hand side but differs by its right-hand side which is lower in (20). Condition (20) is thus more stringent than condition (15). It implies that all target fishing $\tilde{X}$ that can be implemented with a Pareto-improving IQ regulation can also be implemented with a Pareto-improving FS regulation but the reserve is not true. Ideed, it easy to provide examples in which the fishing effort that maximizes the total welfare from the fishing activity X^* cannot be implemented with a Pareto-improving IQ regulation.

A reduction of fishing effort to a target $\tilde{X}$ that violates condition (20) make the lowest cost fishermen be worse-off under the IQ regulation. It defines a threshold fisherman's cost c^{IQ} such as all fishermen with costs $c < c^{IQ}$ are worse-off and all those with $c \geq c^{IQ}$ are better-off under the IQ regulation than under FA with c^{IQ} defined as:

$$c^{IQ} = \frac{F(X^{FA}) - F(\tilde{X})}{X^{FA} - \tilde{X}} \tag{21}$$

We thus established the following result.[14]

Proposition 2 *A reduction of fishing effort with individual quotas to $\tilde{X}$ is Pareto-improving if and only if*

$$\frac{F(X^{FA}) - F(\tilde{X})}{X^{FA} - \tilde{X}} \leq \underline{c}.$$

For highest fishing effort reductions, only fishermen whose cost is higher than c^{IQ} benefit from the IQ regulation.

The IQ regulation is illustrated in Figure 3 below.

[14] Proposition 2 is consistent with Johnson and Libecap (1982)'s assertion that those fishermen who are the most likely to lose out and therefore to oppose the introduction of individual quotas are the most efficient ones.

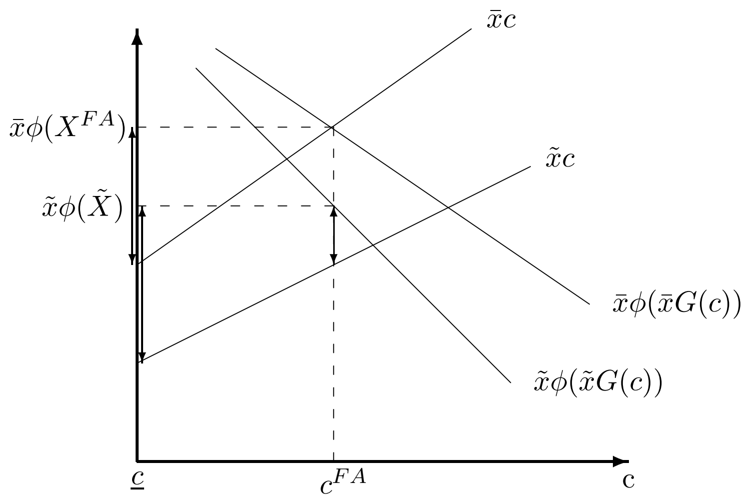


Figure 3. *Regulation with IQ*

The downward sloping curves represent the total product under free access (using full capacity $\bar{x}$) and under IQs (using all effort quota $\tilde{x}$). Here we consider the worst case for fishermen whereby the total revenue is always lower under IQs. The upward slopping curves are total costs. All fishermen with costs up to c^{FA} exhaust their quotas to fish. Every fisherman c earns a strictly positive profit which is equal to the distance between the equilibrium total revenue $\tilde{x}\phi(X)$ and his total cost $\tilde{x}c$. Yet his profit has not necessarily improved compared to the free access regime. Recall that a fisherman c's free access profit is the distance between the free access revenue $\bar{x}\phi(X^{FA})$ and the total cost $\bar{x}c$. Here IQs reduce revenues but also total costs. Although the reduction of revenue is identical for all fishermen, the reduction of total costs is heterogeneous. Those with higher costs per unit of effort experience a higher reduction of total cost and therefore a higher increase of profit. In particular the fisherman with the highest cost c^{FA} obtains the highest profit increase, represented by the right-hand double arrow in Figure 3.[15] On the other hand, the fishermen with the lowest cost $\underline{c}$ get the lowest increase of profit. In Figure 3 this increase is almost nil because the profits under FA and under IQs (the size of the two left-hand double arrows) are almost the same. Formally, it means that the Pareto-improvement constraint (20) is binding. This difference of total

[15] Remember that fishermen c^{FA} make zero profit under free access so that their increase of profit is simply their profit under the IQ regime.

cost among fishermen is due to the difference of slopes of the two total cost curves which increase with lower quotas $\tilde{x}$. By reducing the slope of the total cost curve, IQs tend to "homogenize" fishermen's total costs.

Before moving on to transferable quotas, note that, in our framework, the individual quota can equivalently be defined on individual catch or revenue. An upper bound on catch $\tilde{x}\phi(\tilde{X})$ provides every fisherman with incentives to exhaust their quota, thereby exerting fishing effort $\tilde{x}$ at the equilibrium.

5 Individual and Transferable Quotas

Consider the following individual and transferable quota (ITQ) scheme. As in the preceding section, each fisherman $c \leq c^{FA}$ is assigned an individual level of quotas on effort $\tilde{x}$. But now quotas can be exchanged in a competitive quota market at a price p. The total quota level distributed is $\tilde{X} = \tilde{x}G(c^{FA})$. Quotas have value as long as $\tilde{X} < X^{FA}$ which implied that all quota will be used.

Each fisherman compares the return of one unit of quota in the fishery with its value on the market. By using for himself the quota to fish, a fisherman c obtains $\phi(\tilde{X}) - c$. On the other hand, he gets p by selling this unit on the market. Therefore, a fisherman c prefers to sell (respectively buy) a quota if $\phi(X) - c < p$ (respectively $\phi(\tilde{X}) - c > p$). At the market equilibrium p, there exists $\tilde{c} = \phi(\tilde{X}) - p$ such that all fishermen $c \leq \tilde{c}$ buy quotas up to their capacity $\bar{x}$. Those with $c \geq \tilde{c}$ sell all their quotas and stop fishing. The market clearing condition determines $\tilde{c}$ such that $\tilde{X} = \bar{x}G(\tilde{c})$. The equilibrium price is thus $p = \phi(\tilde{X}) - \tilde{c}$ which is the return of a quota in the fishery for threshold fisherman $\tilde{c}$.

The profit of a fisherman c with ITQ depends on whether he sells or buys quotas. A fisherman with cost $c \leq \tilde{c}$ buys $\bar{x} - \tilde{x}$ units of quota to fish to his full capacity $\bar{x}$. His profit is therefore $\bar{x}[\phi(\tilde{X}) - c] - p(\bar{x} - \tilde{x})$. His marginal cost is c for the first units of effort up to his quota endowment $\tilde{x}$ and $c + p = c + \phi(\tilde{X}) - \tilde{c}$ beyond.[16] Those with $c \geq \tilde{c}$ sell all their quotas at price $p = \phi(\tilde{X}) - \tilde{c}$ and thus obtain $p\tilde{x} = (\phi(\tilde{X}) - \tilde{c})\tilde{x}$ which is also the profit of the threshold fishermen $\tilde{c}$.

To implement a fishing effort $\tilde{X}$, the $\tilde{x}$ quotas assigned to the $G(c^{FA})$ fishermen must

[16] The last equality is due to the market equilibrium condition $p = \phi(\tilde{X}) - \tilde{c}$.

satisfy $\tilde{x}G(c^{FA}) = \tilde{X}$ which, combined with the market clearing condition $\tilde{x}G(\tilde{c}) = \tilde{X}$ yields:

$$\frac{\tilde{x}}{\bar{x}} = \frac{G(\tilde{c})}{G(c^{FA})}.$$

Using the above relationship it is straightforward to write fishermen's profit as in (12) and (13), which formally shows that $\Pi^{FS}(c) = \Pi^{ITQ}(c)$ for every fisherman $c \leq c^{FA}$. Therefore, the ITQ and FS regime assign the same equilibrium profits to the fishermen for any targeted fishing effort $\tilde{X} < X^{FA}$. Hence, from the point of view of the profit-maximizing fishermen and the regulator, the two regulatory instruments are equivalent in equilibrium. We refer to both instruments as "market-based". In the next section we compare the market-based instruments with IQs. We first examine the welfare performance before turning to the distributional impacts of regulations.

6 Comparison of regulations

6.1 Welfare improvement

As it is well-known in the literature, market-based regulations FS and ITQs reduce fishing effort more efficiently than IQs. Under our assumption of heterogeneous fishing costs and competitive quota markets, the FS scheme and ITQs minimize the cost of fishing by self-selecting the most efficient fishermen who fish under full capacity: they implement the target fishing effort $\tilde{X}$ with maximal total welfare for the fishing industry. By contrast the IQ regime keeps all fishermen in the fishery with a reduced activity. All regimes yield the same total return $X\phi(X)$. Yet the aggregate cost of fishing under IQs is higher than under the market-based regulations, formally $\int_{\underline{c}}^{c^{FA}} \hat{x}cdG(c) > \int_{\underline{c}}^{\tilde{c}} \bar{x}cdG(c)$.

Regarding individual welfare, the political feasibility of a regulation might require that a minimum proportion of fishermen (e.g. at least half of them) enjoy a welfare improvement. We show that the market-based regulations FS and ITQs allow a higher reduction in fishing than IQs for *any* given minimal share of welfare improvement among fishermen. We already know from Propositions 1 and 2 that it is true under the Pareto-improvement constraint (welfare improvement for *all* fishermen). Recall that c^{FS} and c^{IQ} define the lowest cost fishermen who enjoys a welfare increased from FA under FS/ITQs and IQs respectively. The same fishing effort $\tilde{X}$ make $G(c^{FA}) - G(c^{FS})$ fishermen better-off under FS/ITQs and

$G(c^{FA})-G(c^{IQ})$ under IQs. By (16) and (21), $c^{IQ} > c^{FS}$ if and only if $\frac{F(X^{FA})-F(\tilde{X})}{X^{FA}-\tilde{X}} > \tilde{c}$ which holds by Proposition 1.[17] Therefore $G(c^{FA}) - G(c^{FS}) > G(c^{FA}) - G(c^{IQ})$: more fishermen improve their welfare from free-access under FS/ITQs than under IQs. The last inequality and definitions (16) and (21) imply that, for a given level of political support (e.g. welfare improvement for a majority of fishermen), a higher fishing effort reduction can be achieved under FS and ITQs than under IQ. In particular, if c^m is the median voter in the fishing community, there exists target fishing efforts $\tilde{X}$ such that $c^{FS} \leq c^m < c^{IQ}$ and, therefore, the FS and ITQ regulations would pass under majority voting while IQs would not. These results are summarized in the next proposition.

Proposition 3 *For a given minimal level of welfare improvement within the population of fishermen, the market-based regulations FS and ITQs achieve a higher reduction of fishing effort from free-access than individual quotas. They also achieve the same fishing effort reduction than individual quotas with more fishermen improving their welfare from free-access.*

Figure 4 represents the distribution of welfare under free-access and regulations.

[17] By assumption $\tilde{X}$ cannot be implemented with a Pareto-improving FS regulation which implies that the inequality in Proposition 1 is violated.

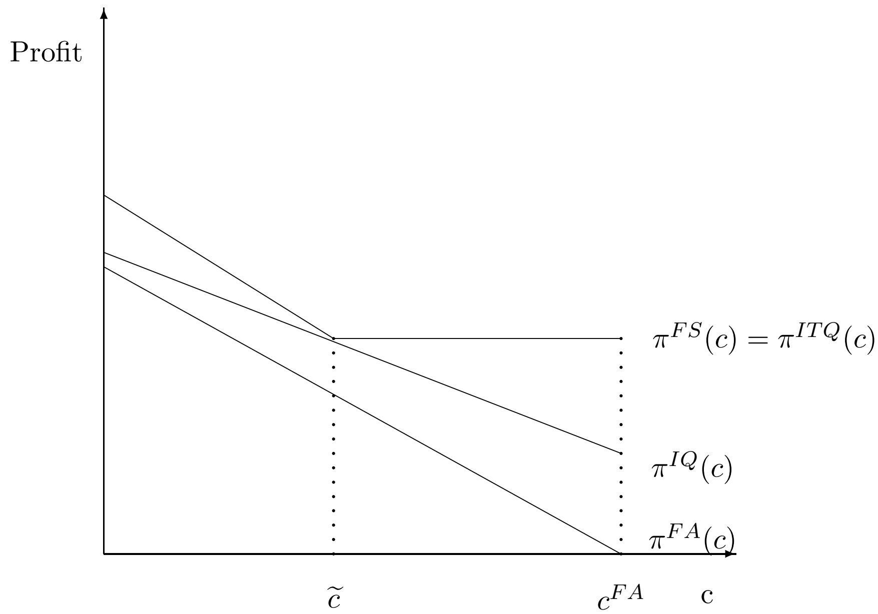


Figure 4. *Welfare distibution*

The three curves are the profit levels $\pi(c)$ for every fisherman c under FA (the lower line), IQs (the middle line), FS or ITQs (the upper kinked curve).[18] They are formally defined in (3), (18), and (12)-(13) respectively. Since the curve $\pi^{FS}(c)$ is above the line $\pi^{IQ}(c)$ except in $\tilde{c}$, all fishermen are better-off under FS/ITQs than under IQs except fisherman $\tilde{c}$ whose welfare is equal under both regulation. Figure 4 represents a target fishing effort reduction $\tilde{X}$ that is Pareto-improving under all regimes. As $\tilde{X}$ decreases, $\tilde{c}$ decreases and the curve $\pi^{FS}(c)$ moves downward. The line $\pi^{IQ}(c)$ also moves downward when $\tilde{X}$ decreases. Moreover, since a lower $\tilde{X}$ requires to implement a lower quota $\tilde{x}$, the slope of the $\pi^{IQ}(c)$ line decreases. It means that a higher reduction in fishing effort reduces welfare differences among fishermen. As $\tilde{X}$ decreases, the two curves $\pi^{FS}(c)$ and $\pi^{IQ}(c)$ move below the curve $\pi^{FA}(c)$ for lower costs c which means that some lowest cost fishermen are worse-off under regulation than under free-access. Since $\pi^{IQ}(c)$ is always below $\pi^{FS}(c)$, it crosses $\pi^{FA}(c)$

[18] Recall that both regimes FS and ITQ yield the same equilibrium profits.

at a lower threshold cost which means $c^{IQ} < c^{FS}$. It implies that more people lose from free-access under IQs than under FS/ITQs for the same target fishing effort $\tilde{X}$.

6.2 Fairness

We examine the fairness properties of the welfare distributions induced by the regulations. We use an axiomatic approach. We rely on the notion of personal responsibility as a foundation for a theory of distributive justice (Fleurbaey, 2008) to define formally fairness principles. Those principles or axioms are applied to the common-pool regulation problem. We then assess to what respect the welfare distribution induced by the regulations satisfy those axioms.

We follow Fleurbaey (2008) by postulating that individuals are or should be held responsible, to some degree, for their achievement. Differences in individual welfare can be justified from a fairness point of view if they are triggered by individual's choices. That is if individuals are responsible for welfare differences through their choices. If not, welfare inequalities are unfair. For sources of welfare differences that are independent of individual's choices, fairness requires to reduce them. Hence, a fair regulation should somehow preserve welfare inequalities inherent to individual's choices (i.e. for which individuals can be held responsible) and reduce welfare inequalities unrelated to individual's choices (for which individuals cannot be held responsible). To apply the notion of responsibility as a fairness principle in our model, we first need to assess the degree of responsibility of fishermen in welfare differences. In our model, the only source of welfare heterogeneity is the extraction cost c. So the question boils down to fishermen's responsibility toward its extraction cost c.

The answer to this question depends on the interpretation of c. Nevertheless, for any interpretation of c, we argue that fishing costs are partly determined by individual's choices and partly not. First suppose that extraction costs are related to skills, high skill fishermen spending less time on sea to catch the same among of fishes. A fisherman can be held responsible for the skill he acquired but not for the skills he inherited. He must be rewarded for having invested in training and education to improve his skills but compensated for his lack of inherited skills (e.g. a handicap). Second, fishing costs can be related to fishing capital and equipments. Fishermen who have invested in more efficient fishing technologies (e.g. less energy intensive boats, new nests,...) should get a fair return on their investment. It implies that they should obtain a higher welfare than those who did not. Yet investment opportunities, in particular access to credit, might be out of a fisherman's own responsibilities. For instance, a fisherman might be born in a wealthy family which might act as a collateral provider. Therefore fishing costs are partly related to circumstances (i.e. whether the fisherman is born in a wealthy family or not) and partly not (i.e. whether the fisherman has invested in cost reduction).

Since we cannot disentangle the responsibility of individuals from circumstances in determining fishing costs c, we define two fairness principles that take into account both individual's and circumstances' partial responsibility on c without making any assumption on the degree of responsibility. Our first criteria acknowledges fishermen's partial responsibility on costs.

Axiom 1 *A regulation R preserves cost ranking if and only if for any c', c'', $c' \neq c''$, $c' < c'' \Rightarrow \pi^R(c') > \pi^R(c'')$.*

The above axiom of cost ranking preservation is a minimal requirement for rewarding more efficient fishermen. Since it does not impose any differences on welfare related to differences in costs, it does not require any assumption on the degree of responsibility on costs. It simply forbids high cost fishermen to obtain the same or a higher return on the fishery than low cost ones. If fishermen have some degree of responsibility on costs, cost ranking preservation should be satisfied. Notice that the axiom can equivalently be defined in term of variation of welfare from free-access: a regulation R preserves cost ranking if and only if $\pi^{FA}(c') > \pi^{FA}(c'') \Rightarrow \pi^R(c') > \pi^R(c'')$ for any c', c'', $c' \neq c''$.

Our second axiom acknowledges fishermen's partial irresponsibility on costs. Circumstances, such that inheritance and luck, impacts also fishing costs. Since fishermen cannot be held responsible for those circumstances, differences on welfare due to circumstances should be eliminated. Since we cannot assess the degree of responsibility of circumstances on cost and welfare, we just require that differences of welfare should be reduced compared to the benchmark free-access regime for all fishermen.

Axiom 2 *A regulation R reduces welfare differences if and only if for any c', c'', $c' \neq c''$, $|\pi^R(c') - \pi^R(c'')| < |\pi^{FA}(c') - \pi^{FA}(c'')|$.*

It turns out that the IQ regulation satisfies the two axioms whereas FS/ITQs satisfy none of them. Clearly since $\pi^{IQ}(c)$ defined in (18) is strictly decreasing in c, it preserves cost ranking for any $c \leq c^{FA}$. Furthermore, since $|\pi^{IQ}(c') - \pi^{IQ}(c'')| = |\tilde{x}(c'' - c')|$ and $|\pi^{FA}(c') - \pi^{FA}(c'')| = |\bar{x}(c'' - c')|$ for any c', c'', $c' \neq c''$, the IQ regulation reduces welfare differences as long as quotas are lower than fishing capacity $\tilde{x} < \bar{x}$. It therefore reduces welfare differences for any target fishing effort $\tilde{X} < X^{FA}$. Welfare differences are reduced further as $\tilde{X}$ decreases, i.e., with more stringent fishing quotas $\tilde{x}$. On the other hand, the market-based regulations FS/ITQs fail to satisfy both axioms. First, they assign the same welfare to all fishermen with $c \geq \tilde{c}$, i.e., those who exit the fishery. Therefore, they do not preserve cost ranking among them. Second, they do not reduce welfare differences among fishermen with $c \leq \tilde{c}$, i.e., those who still fish under regulation. We thus established the following results.

Proposition 4 *Individual quotas preserve cost ranking and reduce welfare differences from free-access. The market-based regulations fail to satisfy both criteria.*

7 Conclusion

Free-access over-exploitation of common-pool resources can be avoided or at least mitigated by regulating extraction. Mainstream regulations include access fee and buy-back subsidies (FS), individual quotas (IQs) and individual transferable quotas (ITQs). The three regulations can all implement the same reduction of resource extraction. They perform equivalently in preserving the resource. Meanwhile, they impact differently user's welfare which affects their political feasibility. Some users win but other might lose and, therefore, be reluctant to regulations. We have analyzed the performance of the above three regulation regimes in reducing resource extraction under the constraint that a given proportion of users do not lose compared to free-access. We have also compared the fairness properties of the welfare distribution induces by the three regulations.

An important assumption of our model is that users differ on extraction costs. Consequently, an efficient reduction of resource exploitation requires to exclude the high cost users. This is made possible with the market-based regulations FS and ITQs. By contrast, under individual quotas, all users extract the resource with reduced capacity, thereby leading to higher extraction costs at the aggregate level. Therefore quota transferability increases total profit as well as individual profits at least weakly. We show that it expands the set of extraction rates (or extraction efforts) that can be implemented under the political feasibility constraint of welfare improvement for a minimal number of users compared to the laisser-faire. In particular, the first-best extraction rate can be achieved with Pareto improvement from free-access under market-based regulations FS and ITQs but not under IQs. Furthermore, the same extraction rate obtains more political support under FS and ITQs than under IQs in the sense that more users experience a welfare increased from free-access.

Fairness also determines the political feasibility of regulations. We argue that individual quotas have attractive fairness property. The quota regulation both reduces inequality among all users and reward the more efficient users for their past investment in cost reduction. By contrast, the market-based regulations FS and ITQs fail to satisfy both criteria. This last result might explain why non-tradable individual quotas are widely used in practice to regulate common-pool resources despite their poor performance in term of welfare improvement compared to market-based instruments.

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