Economic Efficiency of Alternative Bycatch-Reduction Policies and Bycatch Reduction Devices

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Abstract: This paper examines the ability of two new policies to reduce bycatch of red snapper by the shrimp fishery in the Gulf of Mexico: Fractional License and Fractional Gear Programs, as proposed by Townsend, reduce bycatch by reducing the effort levels of shrimp vessels. The policies are evaluated both theoretically and using a simulation model, and they are compared with the current regulatory policy requiring shrimp vessels to use bycatch reduction devices to rebuild red snapper stocks. We find that either a FL program or a FG program could reduce effort and the related problem of bycatch resulting in improving red snapper stocks, while at the same time increasing economic welfare in the fishery compared with the impacts of bycatch reduction devices.

Key Words: Fractional License, Fractional Gear, Bycatch, Effort Reduction, Shrimp, Red-Snapper.

I. Introduction

Bycatch or incidental catch is a common problem in most fisheries around the world. Between 18 and 40 million tons are discarded annually by commercial fisheries, making up 20-25% of total harvest (Alverson et al., 1994). Bycatch not only reduces fish population, but also wastes a potentially valuable food source. These issues have led to international efforts to reduce bycatch (FAO, 1995; Japanese Fisheries Agency, 1995). In the United States, bycatch issues are addressed in the Magnuson Fishery Conservation and Management Act (MFCMA).

Regulations to reduce bycatch and discards have been focused primarily on gear modification such as bycatch reduction devices (BRDs) rather than effort reduction. For example, BRDs have been used in the Australian commercial trawl fishery (Government of Western Australian, New South Wales Fisheries) and the commercial shrimp fishery in United States. In an effort to reduce bycatch by shrimp vessels, the 1998 Amendment 9 to the Fishery Management Plan for the shrimp fishery of the Gulf of Mexico mandated the use of certified BRDs on most shrimp trawls in federal waters in the Gulf of Mexico. However, two problems exist with the current bycatch policy. First, the use of BRDs has imposed substantial costs on shrimp vessels due mainly to a loss of shrimp from their nets (Gillig et al., 2001). Second, BRDs have not achieved the 50% reduction of juvenile red snapper bycatch that is the goal set by the National Marine Fisheries Service (1995).[1]

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[1]Gillig et al. (2001) reports bycatch reduction rates of 0% for fish less than 1 year old and 44.5% 1 year old fish.

An alternative to gear modifications, would be to diminish the level of bycatch by reducing effort in the shrimp fishery. Effort reduction is quite attractive because it can benefit both the targeted and non-targeted species and increase the economic value of both fisheries. Pascoe (1997) insisted that the most desirable way to tackle the bycatch problem is to reduce the total effort toward fishing. For example, effort reduction has been identified as the most effective way to reduce bycatch of Baltic harbor porpoises (ASCOBANS). Similarly, the International Council for the Exploration of the Sea (ICES) recommended effort reduction in European Union fisheries so that bycatch was reduced effectively in European Union waters of Danish and UK fisheries (ICES 2002).

In the U.S., however, some effort reduction policies are either illegal or infeasible. The MFCMA prohibits policies that reduce effort through taxation and, in recent years, there has been a moratorium on the use of individual transferable quotas (ITQ). Even if the ITQ moratorium were eliminated, Rettig (1995, p. 448) comments that “ITQ programs are rejected as unworkable in the US Gulf shrimp fishery, where shrimp can be transferred to small trucks in a vast number of bayous.”

The primary goal of this paper is to conduct an economic analysis of alternative policies aimed at reducing the effort levels, thereby reducing the bycatch. The policies considered are called fractional license (FL) (Townsend 1992) and fractional gear (FG) (Townsend and Pooley 1995). Under a FL program, vessels are granted rights to a partial license rather than a complete license. The fractional rights can then be traded among the vessels so that only a portion of the original vessels remain. Under a FG program, vessels are given limited rights to use fishing gear, but can increase their gear by purchasing rights from other vessels.

Such programs are increasingly receiving attention by fisheries management agencies. FG programs have been used in the Southern and Western Australia rock lobster fisheries. In the Southern program a 15% reduction in the number of lobster pots was achieved (Staniford 1988) and a 10% reduction was sought in the Western rock lobster fishery (Jarrett 1999). In these programs, vessels are granted permits for a specific number of lobster pots. For example, when a 10% reduction in effort is required, the management agency would simply reduce each vessel's permits by 10%. Vessels are then allowed to trade permits among themselves as long as the total number of pots does not exceed the cap. In the U.S., a program similar to a 50% FL program is being considered for the Gulf shrimp fishery (Gulf of Mexico Fishery Management Council, 2003)[2].

Despite the growing interest by managers, however, a complete and comparative analysis of such approaches is lacking in the literature. Stanford provides a theoretical and empirical model of FG programs for the Southern Australia Rock Lobster fishery. Here we add analysis of theoretical and simulation-based analysis of the FL and FG programs and evaluate their ability to reduce effort and bycatch of juvenile red snapper in the shrimp fishery of the Gulf of Mexico. We first build theoretical models for FL and FG policies, building on work by Anderson and Staniford. We then present simulation analysis of the FL and FG policies for the joint shrimp-red snapper fisheries, which are incorporated into a

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[2] This is one of the proposed options in Amendment 14 of the Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico. In this option shrimp vessels in the economic exclusive zone would be required to acquire two permits and retire one of them.

modified version of the General Bioeconomic Fishery Simulation Model (GBFSM) initially developed by Grant and Griffin (1979).

II. Theory of FL and FG Programs

A. Theoretical model of an heterogeneous open-access fishery

Anderson (1989) provides a basic model of an open-access (OA) fishery with heterogeneous vessels. Figure 1, adapted from Anderson (1989), shows three representative vessels that have different cost structures and the consequent industry effort supply curve. When the market price is constant, average revenue (AR) per unit of effort can be derived from a standard concave sustainable revenue curve leading to the downward sloping AR curve in the far right graph in the Figure 1. The aggregate supply (AS) curve is the horizontal aggregation of supply curves of the vessels, i.e. the marginal cost (MC) curves above the average cost (AC) curves.

The equilibrium effort level of the OA fishery will be where the AS curve intersects the AR curve. At this effort level, the AR per unit of effort is R_0 and each vessel will operate at the effort level at which its MC equals R_0. Notice that the first and second vessels earn rent at the OA equilibrium equal to $(R_0–\mathrm{a})e_1$, and $(R_0–\mathrm{f})e_2$, respectively. Anderson (1989) called this “open-access highliner rent.” The curves have been drawn so that the third vessel is marginal and earns zero rent. Since the efficient effort level of the fishery would be where the MC equals marginal revenue (MR), the OA equilibrium is inefficient and reducing effort would increase welfare in the fishery.

B. A theoretical model of FL and FG programs

Building on the OA model, we now explore the theoretical properties of FL and FG programs. As formulated by Townsend (1992) and Townsend and Pooley, a FL program permanently eliminates a portion of the licenses from the fishery. This is accomplished by granting each vessel a tradable FL right, i.e. a right to a portion of a full license, yet establishing that a vessel can operate only if it obtains a full license. Through trading, some vessels complete their licenses and the remaining vessels exit the fishery. In a FG, system the tradable right is gear-indexed (Townsend 1992) and fishermen can use no more gear than the amount for which they hold a license. The two programs differ, therefore, in that the FL right is with respect to a discrete input and the vessel can only operate if it completes the right, while the right in a FG program is continuous and vessels can operate, perhaps less efficiently, with less than their original level of gear.

We consider first the case of a FL program using Figure 2. Building on Figure 1, we consider here the case of a program with three vessels and a FL program that grants each boat a 2/3 FL right. In other words, one vessel will have to leave the fishery, selling its right to the other two vessels. Because only two of the three vessels can remain in the fishery, the AS curve will shift upward, leading to a new equilibrium at the intersection between the AS_1 and AR with E_2 units of aggregate effort and an AR of R_1. If the vessels held a full license right, they would fish at the effort levels where their MC equals R_1, i.e., e_1^2, e_2^2 and e_3^2, leading to annual rents of $\Pi_1=(R_1-b)e_1^2$, $\Pi_2=(R_1-g)e_2^2$ and $\Pi_3=(R_1-k)e_3^2$, respectively. These potential profits will determine the vessels' willingness to pay (WTP) to complete their licenses and their willingness to accept (WTA) to sell their licenses.[3]

Assuming that trading leads to a permanent transfer of the right from one vessel to another, each vessel's WTP to complete its license will equal the present value of future annual rents, say Π_1, Π_2 and Π_3. When an α percent FL is granted to a vessel with annual rent π_i, the WTP and the WTA per percentage of a full license is $\Pi_i/100$. The WTP and WTA per percentages of a license are $\Pi_i/100$ to each vessel i=1,2,3. Obviously, vessels will be willing to pay only if they can purchase 100-α percentages of a license to complete their license. In Figure 2, the equilibrium price per percentage of a FL will be between $\Pi_2/100$ and $\Pi_3/100$, i.e., greater than or equal to the third vessel's WTP and less than or equal to the second vessel's WTA. At this equilibrium price the third vessel will sell all fractions of its license and exit the fishery. The first and second vessels, whose WTP and WTA per percentage of a license are greater than the equilibrium price, will buy the fractions from the third vessel, and create e_1^2 and e_2^2 units of fishing effort, respectively. Note that because vessels 1 and 2 increase their effort in response to the higher AR, aggregate effort does not fall all the way to $E_1=e_1^1+e_2^1$. Hence, effort will typically fall by less than α%.

The model of a FG program is similar and is presented in Figure 3 based on Staniford. Each vessel's costs are a function of multiple inputs, including the gear to be

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[3] We assume here that neither buyers nor sellers exhibit market power in the market. While this appears implausible in the case presented here with only two buyer and one seller, in true market with many buyers and sellers, such an assumption is more reasonable.

regulated, *k*. For simplicity, we assume zero fixed costs so that a vessel's profits are now equal to the area below the AR and above the MC curve. We start after an α% reduction in the vessels' gear, so that they have rights to use k_1^1, k_2^1 and k_3^1 units of gear. Because the gear is restricted, the MC curves of the vessels will kink up at the point where the efficient generation of effort uses these gear levels, at the points marked b, f and g. The MC curves under the gear limitation before trading are shown as $MC_1(k_1^1)$, $MC_2(k_2^1)$ and $MC_3(k_3^1)$ in Figure 3, and sum to AS_1. The intersection of the AR and AS_1 curves determines the increased revenue R_1 per unit of effort that would result without trading. The lower set of graphs indicate the marginal WTP and WTA for rights to gear. The annual rent of the first vessel under a FG before the trade of gear units is the area R_1abc.

Hence, the minimum amount that the vessel would be willing to accept to permanently give up the entire right is the present value of this amount, equal to the area $Oefk_1^1$ in the lower left-hand graph in Figure 3. The area adb is, on the other hand, the annual increase in rents obtained by returning to the cost minimizing level of capital under AR=R_1. The associated WTP to purchase gear rights sufficient to return the vessel to the original level is captured in area *Oeg* in the lower left-hand graph. Likewise, the WTA and WTP curves are drawn for the second and third vessels.

As we have drawn the figure, at the equilibrium price per unit of the FG right, P, the first vessel buys the k_1^* gear rights from the third vessel, and the second vessel's gear rights remain at k_2^1. The trade causes the MC of the first vessel shifts rightward and the MC of the third vessel shifts leftward. Trade will move gear rights to the first vessel from the third vessel as long as the marginal increase in the first vessel's profits is greater than the marginal reduction in the third vessel's profit. As discussed by Staniford, the AS shifts rightward as a result of trading since the first vessel is more efficient in creating effort. This leads to a new equilibrium AR, R_2. At the equilibrium, the vessels will create e_1^2, e_2^1 and e_3^2 units of effort, leading to a reduction in the total effort of the fishery from E_0 to E_2. As was true in the FL market, the effort reduction is less than proportional to the reduction in the gear. In this case there are two effects. First, vessels will tend to increase their effort in response to higher AR. Second, they will substitute other inputs for the gear that has been restricted.

Through the theoretical models we see that either FL or FG can achieve a reduction in fishing effort. In general, neither can achieve the socially optimal level of effort. Because the programs leave room for vessels to expand their effort by, for example, increasing the time spent fishing or using more of unregulated inputs such as horsepower, the programs will still lead to an open access equilibrium where the social marginal cost is greater than the social marginal revenue. Furthermore, these approaches would typically not lead to the cost-minimizing allocation of inputs. Finally, the reduction in effort (and bycatch) will typically be less than proportional to the reduction in the rights allocated. Nonetheless, these programs have advantages over other approaches because the transferability of the rights allows more cost-effective vessels to use the rights and, thereby, increases industry profits. Based on theory alone, it is not possible to rank the two policies in terms of either economic efficiency or their ability to reduce bycatch. With the help of a simulation model, however, in the next section we can carry out such comparative analysis in the context of a specific fishery.

III. A Simulation Model of FL and FG Programs

We now present a simulation model that has been developed to study the potential implications of FL and FG programs in the Gulf of Mexico shrimp fishery. Our simulation analysis makes use of GBFSM, which was originally developed to predict how alternative management policies would affect fisheries (Grant et al. 1981) and has been used extensively for analyzing the effects of management policies in the Gulf of Mexico (Blomo et al. 1978; Grant and Griffin 1979; Griffin and Stoll 1981; Griffin and Oliver 1991; Griffin et al. 1993; Gillig et al. 2001). The model is described in depth in this journal in Funk et al. (2003), and in much more detail at http://gbfsm.tamu.edu. GBFSM consists of two main parts: a biological submodel and an economic submodel. The biological submodel represents the recruitment, growth, movement and mortality of shrimp and finfish. Fish mortality is due to both natural causes and fishing. Effort targeted toward shrimp leads to incidental bycatch of finfish. When a management policy is imposed on GBFSM, the biological submodel is used to calculate the changes in days fished and landings of shrimp and red snapper. The economic submodel then calculates the economic impact on commercial fishermen in terms of costs, revenues, and rent for each vessel class in each area, and the impact on consumer surplus associated with the recreational red snapper fishery (Gillig et al. 2001). Unless entry is restricted by regulations, vessels enter and exit the fishery if rents are positive.

In the current study, the FL and FG programs are applied to the Gulf of Mexico's shrimp fishery with six separate rights markets across the Gulf: one in each state's waters, and one covering the federal waters across the gulf. The model of the FL and FG programs involves three main steps. First, vessel sizes and gear of all licensed vessels in the Gulf are simulated. Second, profits of the vessels are simulated. Based on each vessel's simulated profit function, it is possible to simulate the WTP and WTA for rights for the FL program and for the FG program. Finally, markets for these FL and FG rights are simulated and the market is cleared, reducing the number of vessels participating and, in the FG case, the gear of each vessel. These three steps are discussed below with more technical discussion in the appendix.[4]

Because of data limitations, a vessel's effort is assumed to be a function of only two inputs: the vessel's length and the length of the net that it drags, measured in the length of its *footrope*.[5] The initial distribution of vessels by length is based on data provided by the Southeast Regional Office of NMFS for the beginning of the 1998 license year (National Marine Fisheries Service, 2000). The initial footrope length for each vessel is simulated assuming that, up to error terms from the empirical distribution, each vessel has chosen its gear to maximize the net present value (NPV) of the fishing profit.

The second step is to simulate profits of the vessels in the fishery. As seen in the theoretical model, when faced with a fractional license or fractional gear, a boat owner will buy or sell licenses up to the point where the marginal value of a right is equal to the market price. Hence, in order to simulate the effects of a FL or FG market, it was necessary to specify and estimate a parametric representation of the profit function for the vessels in the fishery. Ideally, an annual profit function would be estimated. However, the necessary cost and return data available were only available on a trip by trip basis. Hence, a daily profit

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[4]Substantially more detail is provided in Wui (2002) or Woodward, Griffin and Wui (2003).

[5]Shrimp vessels use an otter trawl to catch shrimp. That trawl is measured by footrope length.

function was used, assuming that the i^{th} vessel's daily revenue and cost in period t, R_{it}^{d} and C_{it}^{d}, take the forms

$$(1) \qquad R_{it}^{d} = \exp\left(a_0 + a_1 \ln\left(L_{it}\right) + a_2 \ln\left(F_{it}\right) + \varepsilon_{Rit}\right) \text{ and } C_{it}^{d} = b_0 + b_1 L_{it} + b_2 F_{it} + \varepsilon_{Cit},$$

where L_{it} is the vessel's length and F_{it} is the length of the vessel's footrope. These functional forms were particularly attractive because they allowed us to obtain analytical solutions for the market equilibrium. The econometric model and estimated parameters is discussed the appendix. To annualize profits, vessels in each market are assumed to fish the average number of days for the market.[6] Again drawing residuals from the empirical distributions, we then simulated profit functions for each vessel in the heterogeneous fleet.

The equilibrium of the FL market is relatively straightforward and is the direct application of the theoretical model as presented in Figure 2. After each vessel's profits are simulated, its WTP and WTA for FL rights can be calculated as the present value of future annual rents, Π_i . Vessels are then ordered and the vessels with the lowest WTP exit the fishery. The market-clearing price per FL percentage is then calculated as the highest WTA of an exiting vessel.

As seen in Figure 3, the equilibrium of the FG model is somewhat more complicated because the price affects not only the level of gear that a boat desires to hold, but also the decision of whether or not the vessel chooses to remain in the fishery. Simulating the FG

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[6] The number of days for each market was calculated at the end of each simulated year as the ratio of number of days simulated by GBFSM divided by the number of licenses in the market.

market, therefore, requires an iterative two step process. First an equilibrium price is found holding the number of vessels participating constant and assuming that each vessel maximizes the present value of its profits. Then the number of vessels is adjusted after eliminating from the fishery those vessels that would prefer to exit the fishery and sell their entire allocation of rights. This two-step process is repeated until an equilibrium is found where all vessels in the fishery are holding the profit maximizing level of gear and vessels that would prefer to exit the fishery sell all of their gear rights. To avoid unreasonable combinations of gear and boat length, we assume that the length of a vessel's footrope cannot change by more than 20%.

After imposing a FL or FG program, the fleet is then reintroduced into the main GBFSM modules to simulate harvests, stock changes and economic benefits. For the current analysis, GBFSM is initialized so that the shrimp fishery is at a bioeconomic equilibrium where average rents are zero. The introduction of a FL or FG policy pushes the fishery out of equilibrium and the fishery moves towards a new equilibrium over the next several years. This results in a change in the producers' and consumers' surplus. To calculate the PV of the benefits of a policy, the annual discount rate of 7% is used as required in the Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs (Executive Office of the President).

IV. Results of Simulation Analysis

Four scenarios will be examined in this paper (Table 1): Base, BRDs, FL, and FG. As shown in Table 1, the Base scenario replicates the 1998 policy mix, including a cap on the total allowable red snapper catch (TAC), a bag limit per trip, etc. However, in the Base scenario it is assumed that the BRDs are not used. To facilitate comparisons with the alternative scenarios, in the Base scenario the model is calibrated so that the shrimp fishery is in OA equilibrium. This is accomplished by adjusting the opportunity cost of the average vessel owner until there is no entry or exit. As a result of this calibration, predictions as to the relative impacts of the policies are clearer, but quantitative predictions of the model should be regarded with caution.

Each of the other scenarios then add one additional policy on top of the suite of base-case policies. The BRD case simulates the fishery with BRDs imposed on shrimp fishery. Five FL and five FG scenarios are evaluated with reductions of 10, 20, 30, 40 and 50% in number of licenses and in the total length of footrope, respectively. In the FL (FG) scenarios, a one-time reduction in shrimp licenses (footrope) occurs at the end of the first year of the simulation, and the FL (FG) markets determines who will remain in the shrimp fishery at the beginning of the second year. The FL (FG) markets continue to operate at the end of each year, although no additional reduction in licenses (gear) is imposed. Each scenario is evaluated from 1998 to 2032, a thirty-five year time period.

A. Base Scenario

Because the Base scenario is calibrated at the open-access equilibrium, real fishing effort is constant at 226.9 thousands fishing days across the Gulf of Mexico over the 35-year simulation period.[7] Without BRDs in the shrimp fishery and under the 1998 policy suite for the red snapper fishery, the model predicts that red snapper stocks will decline from 33.7

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[7]Real effort is calculated by multiplying the relative fishing power of a vessel class by the nominal fishing days of that vessel class (Griffin, Shah, and Nance 1997).

million pounds in 1998 to 16.2 million pounds by 2032. As a result of these falling stocks, bycatch of red snapper is predicted to decrease over time despite the constant effort in the shrimp fishery. The NPV of shrimp producer and consumer surplus over the 35-years was $1,277 millions, as shown in Figure 4.

B. BRD Scenario

When BRDs are added to the Base scenario management policies there are two consequences as shown in Figure 4. First, because of the decline in red snapper mortality, the model predicts a red snapper spawning stock biomass by year 2032 of 188 million pounds, much greater than the stock predicted under the Base scenario. Second, BRDs lead to a reduction in harvests and an increase in operating costs in the shrimp fishery. Even though the market price for shrimp is predicted to increase, the quantity effect dominates because of the inflexibility of shrimp price (Gillig, Capps and Griffin 1998) so that both producer and consumer surplus fall. Producer surplus is also negatively affected by the $100 increase in the annual cost per vessel for purchasing and installing the BRDs. In net, therefore, the increase in red snapper stock comes at a cost of slightly more than five percent of the producer and consumer surplus in the shrimp fishery.

C. FL Scenario

While BRDs reduce bycatch directly, a FL policy reduces it indirectly by attempting to reduce effort through a reduction in the number of licenses. As seen in Figure 4, as the FL rate increases, the spawning stock biomass of red snapper shows ever increasing levels of recovery. Indeed, with FL rates of 40 or 50%, higher red snapper spawning stock biomass is achieved than with the BRD scenario. Unlike the BRD scenario, however, the FL program leads to economic benefits for the shrimp fishery. For example, a 40% FL policy is predicted to lead to more than a 30% increase in the producer's surplus in the shrimp fishery, so that even taking into account a 5% decline in consumer surplus, the present value of total surplus for the shrimp fishery is predicted to increase by 32%. Over the range of policies considered, we find greater reductions in the number of licenses in the fishery lead to ever increasing levels of total surplus and spawning stock of red snapper.[8]

D. FG Scenario

As in the FL scenarios, the FG programs tend to increase surplus in the shrimp fishery while at the same time helping the recovery of the red snapper stocks. However, the FG program is not as cost effective as the FL program. As seen in Figure 4, to reach a stock level comparable of that achieved through BRDs, the model estimates that a 40% reduction in gear would be required, while only slightly more than 30% of the licenses would achieve the same stock recovery. Moreover, although FG programs tend to increase the NPV of surplus in the shrimp fishery, for comparable red snapper stock levels, the economic benefits to the shrimp fishery are strictly dominated by those achieved through a FL program. The economic disadvantage of the FG programs is probably attributable to the fact that the FG program tends to push vessels away from their cost minimizing input allocation. In fact, at the 20% level, the FG program actually causes a slight decline in total surplus in the fishery relative to the Base scenario.

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[8]Obviously, the precision of the model's prediction will decline as policies depart further from the status quo. We are confident in the qualitative nature of the results, but quantitative predictions should be viewed with some caution.

V. Conclusions and Discussion

If a policy objective is to reduce bycatch, we find that effort reduction is an attractive alternative to an input-based BRD policy. FL or FG are ways to achieve effort reduction and merit consideration. While BRDs tackle the bycatch problem directly by restricting the trawls of shrimp vessels without considering the economic consequences, FL or FG programs solve the bycatch problem indirectly by reducing effort. Hence, FL or FG policies address both the bycatch problem and the problem of excess capacity in the shrimp fishery. Effort reduction is always difficult to achieve in practice because fishermen are typically reluctant to stop or scale back their fishing. However, in FL or FG programs, fishermen are given limited rights to fish, which they can voluntarily sell if this ends up being more profitable. Hence, as Townsend (1992) noted, FL or FG programs might be implemented more easily than many other effort reduction policies.[9]

Our empirical analysis of the shrimp and red snapper fisheries of the Gulf of Mexico, finds that FL or FG policies are preferred to the current BRD policy since these approaches can lead to equivalent benefits to the red snapper fishery, while at the same time providing economic benefits to the shrimp fishery. The results should be interpreted with some degree of caution as high FL and FG rates could induce fundamental changes in the shrimp fishery that cannot be anticipated based on existing data. With this caveat, however, we believe that there is strong support for our qualitative conclusion: effort reduction through transferable

[9] We have not addressed any cost that might be required to implement or enforce a FL or the FG program.

rights programs such as FL or FG is an appealing alternative to the problem of bycatch in fisheries.

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Table 1. The management policy scenarios of shrimp and red snapper fisheries evaluated using GBFSM

Management Policy Scenarios		Policy Description
Base[a]		Total Allowable Catch (TAC) =9.12 million pounds in red snapper TAC allocation Commercial red snapper =51% Recreational red snapper=49% + a 10% overage [b] Recreational bag limit in red snapper=4 fish/trip Split commercial season in Red snapper Size limits for both recreational and commercial fishermen
BRDs [a, c] (1998 current policies)	Base +	All the offshore shrimp vessels are required to use BRDs except lower Florida and part of upper Florida. Reduction of age 0 red snapper=0% Reduction of age 1 red snapper=44.5% Shrimp loss=6.5% Survival rate of shrimp loss=50%
FL	Base +	Shrimp license reductions of 10,20,30,40 or 50%
FG	Base +	Shrimp gear reductions of 10, 20, 30, 40 or 50%

[a] Source: Gillig et al, 2001.

[b]A 10 percent overage is used as a conservative attempt to account for the inability of current monitoring procedure to accurately track harvest to facilitate closure when the allocation is filled. The average overage for the 1997 and 1998 fishing seasons is 23 percent.

[c] The use of the Super Shooter Turtle Exclusive Device and fisheye BRD (allowing different placement positions).

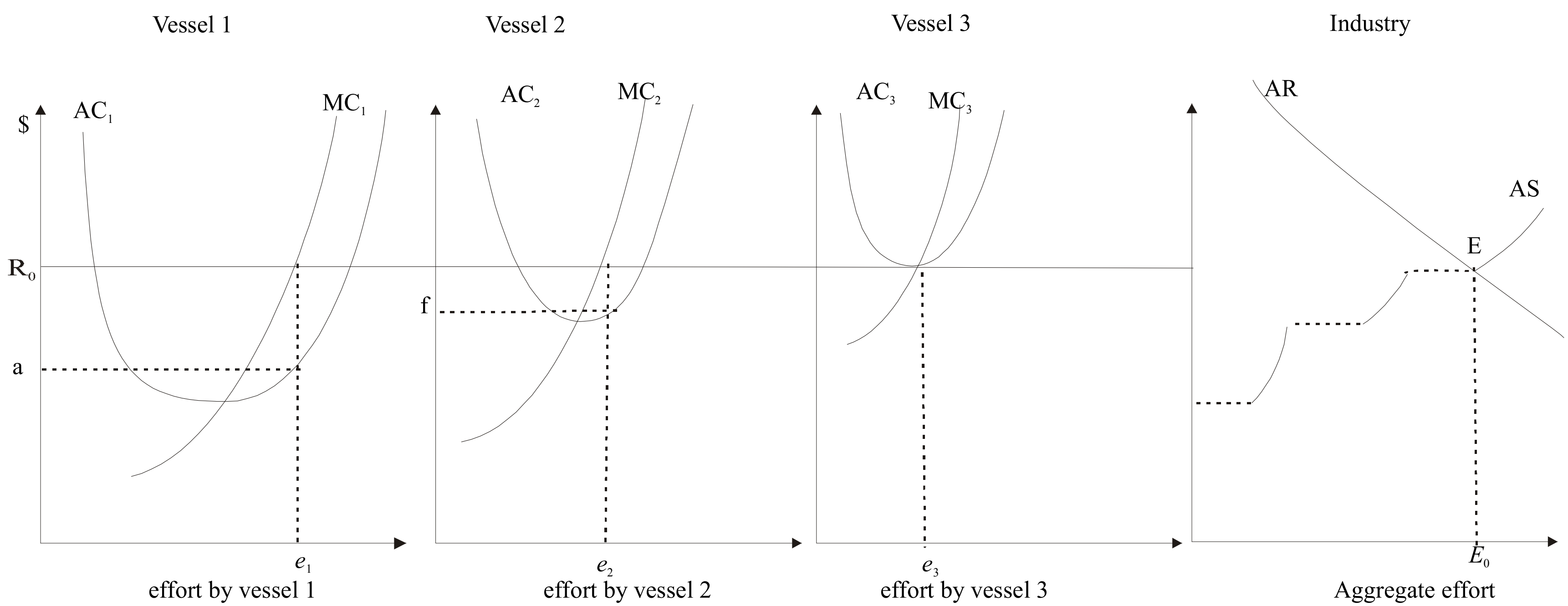

Figure 1. Open access fishery with heterogeneous vessels (adapted from Anderson)

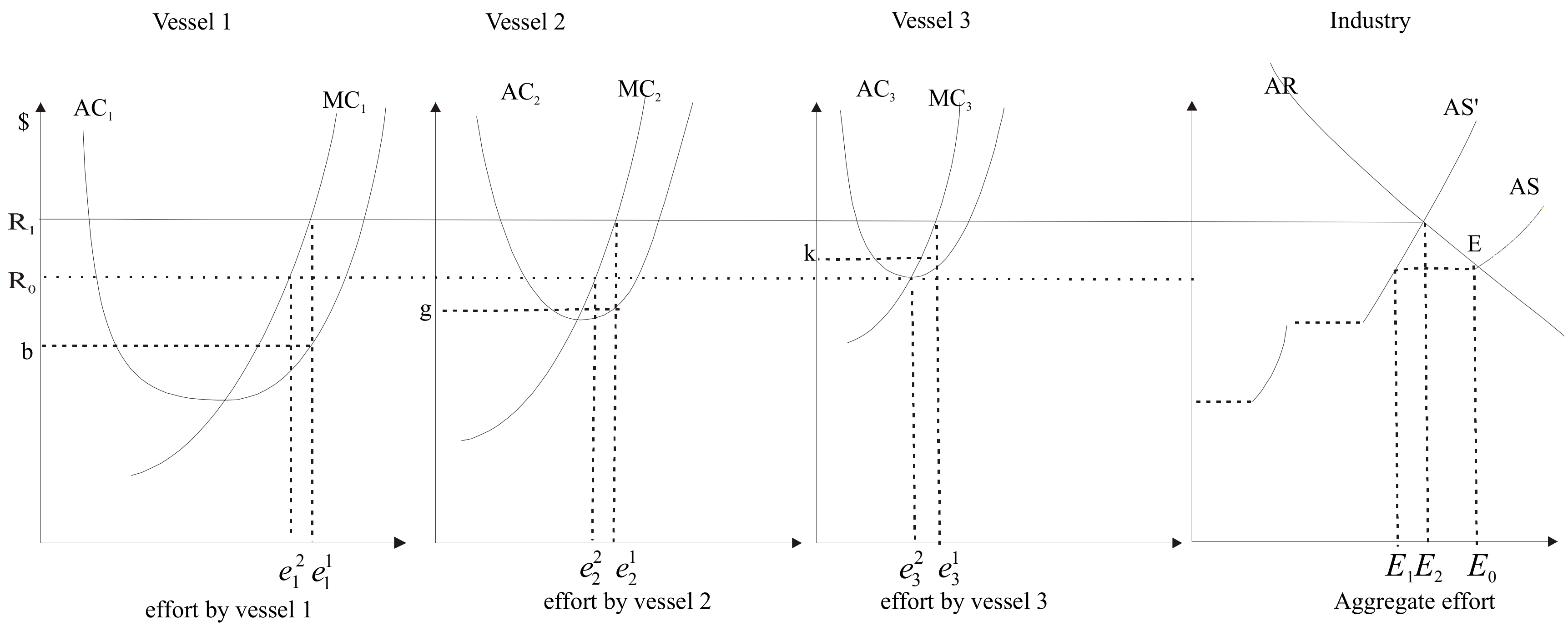

Figure 2. FL granted to vessels and their WTP and WTA

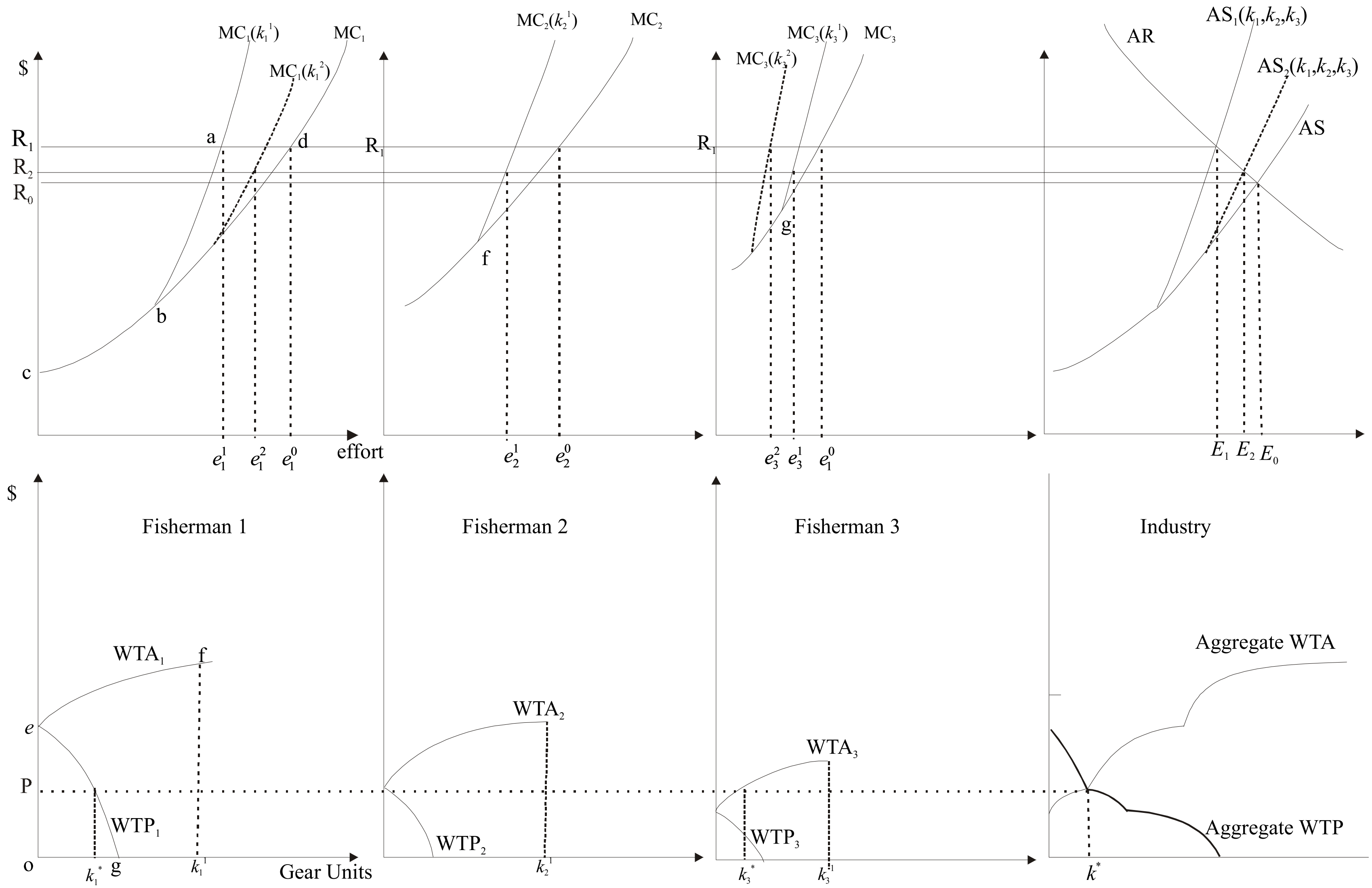

Figure 3. FG granted to vessels and their WTP and WTA (adapted from Staniford)

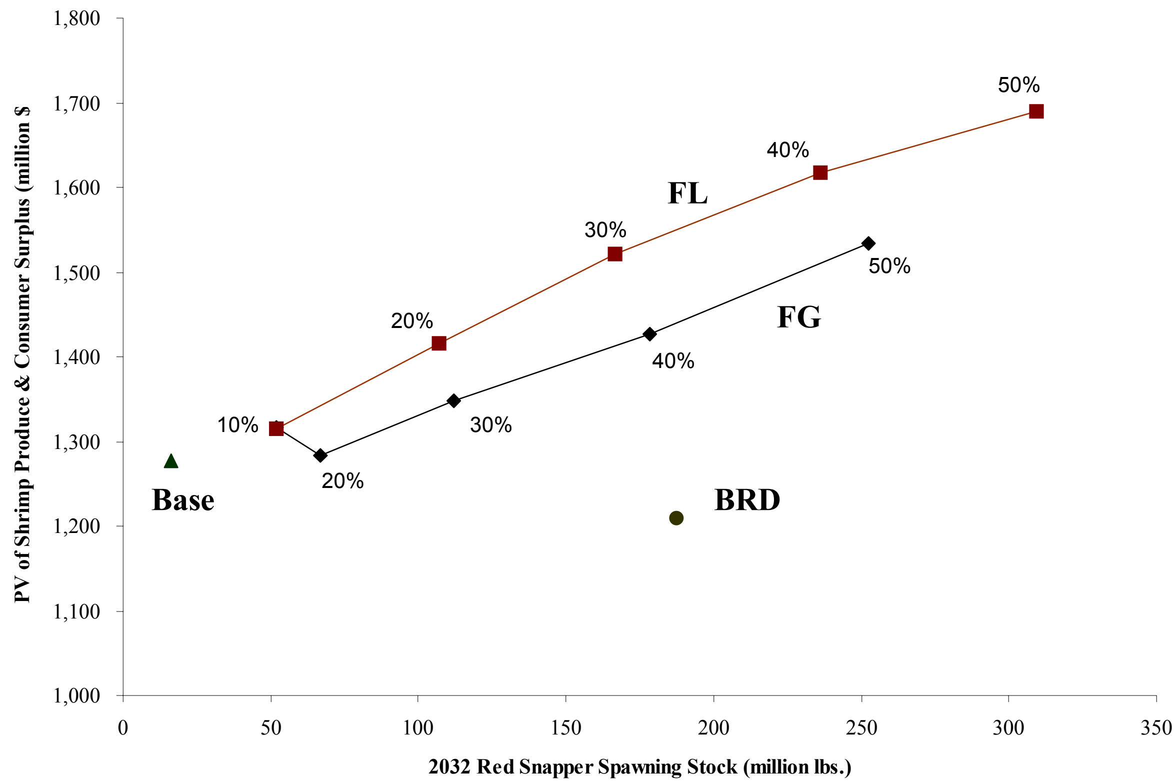

Figure 4. Tradeoff between the change from the base year scenario in the present value of total (producer and consumer) surplus of shrimp fishery and in the red snapper spawning stock biomass (in year 2032) under FL and FG scenarios

Appendix: Specification and estimation of profit function

It was assumed that the vessel's daily profit revenue and cost were exponential and linear as specified in (1). If gear, F_i, is permanent and we assume the fishery is believed to be in a steady state, a vessel owner would choose F_i to maximize the present value of net rents:

(A.1) $$\max_{F_i} \sum_{t=0}^{\infty} (1+r)^t \pi_i\left(F_i \mid L_i\right) = \pi_i\left(F_i \mid L_i\right) \big/ r = \left(R_{it}^d - C_{it}^d\right) \big/ r$$

where r is the daily discount rate. The first-order condition for this problem can be written

(A.2) $$\ln\left(F_{it}\right) = \left[a_0 + \ln\left(a_2\right) - \ln\left(b_2\right) + a_1 \ln\left(L_{it}\right) + \varepsilon_{Rit}\right] \big/ \left(1 - a_2\right).$$

From this expression we then arrive at the first of three equations estimated:

(A.3) $$\ln\left(F_{ijk}\right) = \frac{a_0 + \sum c_i YD_i + \sum d_j MD_j + a_1 \ln\left(L_{ijk}\right) + \ln a_2 - \ln b_2 + \varepsilon_{Rijk}}{1 - a_2} + \varepsilon_{Fijk},$$

where F_{ijk} represents footrope size of i^{th} year, j^{th} market , k^{th} vessel. YD_i and MD_j represent i^{th} year dummy variable and j^{th} market dummy variable, respectively. The remaining two equations are the reduced form of the cost and revenue equations, leading to the three equations to be estimated empirically were:

(A.4) $$\ln\left(F_{ijk}\right) = \gamma_1 + \sum \alpha_i YD_i + \sum \theta_j MD_j + \gamma_2 \ln\left(L_{ijk}\right) + \varepsilon_{Fijk}$$

(A.5) $$\begin{aligned} C_{ijk} &= b_0 + \sum e_i YD_i + \sum f_j MD_j \\ &\quad + b_1 L_{ijk} + \gamma_3 L_{ijk}{}^{\gamma_2} \exp\left(\varepsilon_{Fijk}\right) \prod \exp(\alpha_i YD_i) \prod \exp(\theta_j MD_j) + \varepsilon_{Cijk} \end{aligned}$$

(A.6) $$\ln\left(R_{ijk}\right) = \gamma_4 + \sum \alpha_i YD_i + \sum \theta_j MD_j + \gamma_2 \ln\left(L_{ijk}\right) + a_2 \varepsilon_{Fijk} + \varepsilon_{Rijk},$$

where, $\gamma_1 = \left[\frac{a_0}{1-a_2} + \frac{\ln a_2}{1-a_2} - \frac{\ln b_2}{1-a_2}\right]$, $\gamma_2 = \frac{a_1}{1-a_2}$, $\gamma_3 = b_2 \exp(\gamma_1)$, $\gamma_4 = a_0 + a_2\gamma_1$, $\alpha_i = \frac{c_i}{1-a_2}$,

and $\theta_i = \frac{d_i}{1-a_2}$.

The estimated coefficients were then transformed into the coefficients presented in Table A.1, which were used in the simulation model. Where transformation of variables was necessary, the associated t-statistics are not reported.

Table A.1. The parameters of exponential revenue and linear cost functions

Revenue Function			Cost Function		
Coefficient	Estimate	absolute t-statistic	Coefficient	Estimate	absolute t-statistic
a_0	3.615	*	b_0	-401.79	8.72
a_1	0.688	*	b_1	23.06	37.97
a_2	0.295	*	b_2	13.70	*
θ_1	-0.072	13.76	f_1	110.98	6.00
θ_2	-0.143	23.48	f_2	146.92	6.70
θ_3	-0.137	19.64	f_3	-244.24	9.90
θ_4	-0.074	17.55	f_4	-51.54	3.29
θ_5	-0.029	6.03	f_5	0.25	0.01
R^2	0.1182		R^2	0.2357	

Note: The coefficients of the dummy variables associated with years are not shown because these were used only in the estimation, not in the simulation. 1998 was simulated as base year.

α_i 's represent the constant and the coefficients of vessel size and footrope size in logarithmic value respectively (*i=0, 1, 2*).

b_i's represent the constant, and the coefficients of vessel size and footrope size variables respectively (*i=0, 1, 2*).

θ_i and f_i's represent the coefficients of i^{th} market dummy variables (i=0, …,5).