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Vessel Buybacks in Purse Seine Tuna Fisheries: The Role of Auction and Financing Structures

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Executive Summary

In this paper, we explore the use of vessel buyback auctions to address issues of overcapacity and excess capitalization in fisheries with limited entry. A vessel buyback program is a decommissioning scheme in which a regulatory authority buys out existing vessels from a fishery and retires them in order to reduce the number of vessels vying for a particular fish stock. While such programs do not entirely eliminate incentives to overcapitalize for those boats that remain in the fishery, they can reduce industry-wide capacity for some time. They can also play an important role in smoothing the transition to a rights-based management regime by rationalizing the market and easing enforcement by limiting the number of participants over which property rights must be allocated.

Our simple theoretical model of a self-financing buyback program implemented in a fishery comprised of vessels that differ in their skill and/or cost structures generates several key insights. First, the financing structure under the buyback can have profound impacts on auction outcomes. A homogenous financing rule that spreads the costs of the buyout evenly across all vessels will result in smaller buyouts than one that spreads costs across boats based on their increased profits under the newly consolidated fishery. The magnitude of this difference is increasing in the heterogeneity of profits across vessels within the fishery.

Second, the structure of the auction itself also matters. A sequential auction that buys one boat at a time until equilibrium is reached will generally result in a smaller buyout than one that announces a one-time schedule of offers to pay a given price for a specified number of vessel retirements (TOLI). The former mirrors the structure of a typical open-ascending auction while the latter resembles a closed-descending price auction. As is typical in these auction structures, the sequential auction leads to a larger transfer of wealth from buyers to sellers. Thus, the sequential auction results in a smaller and less cost-effective buyout than the TOLI auction since the cost per bought out vessel is higher under this structure.

The theoretical modeling is followed by a stylized case study of a TOLI auction inspired by the Inter-American Tropical Tuna Fishery. As predicted by the theory, the heterogeneous financing rule always yields a larger buyback than the homogenous one. When all vessels are assumed to face the same well capacity constraint, these differences are relatively modest, ranging from 12-30%. In all cases, the buyback would reduce the size of the existing fleet by at least one-half, reflecting the sizable difference in vessel profitability within the fishery.

When the assumption of uniform well capacity is relaxed, buyback outcomes change considerably. While the heterogeneous rule still generates a sizable buyout that ranges between 40 and 50 percent of vessels, the homogenous tax system yields very few and in some cases zero buybacks. This occurs because small but highly skilled boats are too expensive per unit of fish to buy out and unwilling to contribute much to the buyback since they cannot absorb much additional catch. It is also noteworthy that an imperfect heterogeneous financing mechanism based on catch is nearly as effective as the perfect one based on profitability. The empirical analysis consistently underscores the importance of having reasonable estimates of vessel-level financial gains from a buyback in order to design a successful auction.

I. Introduction

For most of human history, fisheries, like most natural resources, have been treated as a common resource. Anyone with the means could extract fish from the common pool and since all participants are in competition for a (quasi-) finite resource, overexploitation arises. As new fishing technologies became available, this competition also led to overcapitalization as fleets raced to catch more of the resource. This tragedy of the commons arises because property rights over the fish are poorly defined, such that no individual has an incentive to conserve the resource for fear that others will consume it (Gordon, 1954 and Scott, 1955). As such, economists have advocated privatizing the resource as a means of avoiding overcapitalization and overexploitation (Gordon, 1954 and Scott, 1955).

In the decades since the early writings on this subject, economists have generally coalesced around the use of individual transferable quota (ITQ) systems as the preferred structure for privatization. ITQs are essentially a form of cap-and-trade system, where the total harvest for a given year, known as the total allowable catch (TAC) is fixed and individuals are allocated a fixed share of that catch which they can freely trade with others. While the economic success of ITQ systems have been well documented in the locations in which they have been implemented (see, for example, Grafton et al., 2000; Hannesson, 2004; and Newell et al., 2005), less than two percent of fisheries around the world use anything resembling an individual quota system, transferrable or otherwise (Costello et al., 2008).

Given the practical difficulties in the adoption of ITQ systems, which largely stem from the formal allocation of property rights and the resulting distributional shifts in rents associated with this transition (see Barrett (2003) and Libecap (2008) for a general discussion of this problem), many fisheries have employed an intermediate policy to protect fisheries from collapse – limited entry. In this system, individuals generally must have a permit to fish and a cap on the fishery-wide catch is established, either explicitly through a TAC or implicitly through restrictions on fishing seasons, gear types, and/or allowable areas fished. While this approach limits overexploitation of the resource by fixing the total catch (at least when the TAC is appropriately determined), it does little to limit capital stuffing by those vessels in the fishery, since the absence of individual quotas still leaves each fisherman with a strong incentive to outcompete others in order to capture the largest share of the TAC possible.[1]

In this paper, we explore the use of vessel buyback auctions to address issues of overcapacity and excess capitalization in this policy setting. Overcapacity of productive capital in a fishery is inefficient for all involved, and increases the likelihood of (by creating the capacity for) extraction beyond any TAC in place. A vessel buyback program is a decommissioning scheme in which a regulatory authority buys out existing vessels from a

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[1] TAC limits may in fact exacerbate overcapitalization concerns, as such limits increase the potential value of additional productive capital. In addition to forcing players to compete for a smaller pie, the restriction of total supply may lead to price increases for the goods produced, increasing the marginal revenues of

fishery and retires them in order to reduce the number of vessels vying for a particular fish stock. While such programs do not entirely eliminate incentives to overcapitalize for those boats that remain in the fishery, they can reduce industry-wide capacity for some time. They can also play an important role in smoothing the transition to a rights-based management regime by rationalizing the market and easing enforcement by limiting the number of participants over which property rights must be allocated (Squires, 2010).

Vessel buyback programs along with other forms of decommissioning schemes focused on the acquisition of fishing licenses or gear have been deployed in a handful of fisheries with mixed success (see Curtis and Squires (2007) for a review). While the ultimate impacts of these programs has been idiosyncratic to the fishery and policy specifics, there is a general consensus that all such programs have been rather inefficient – with budgeted funds garnering lower levels of capacity reduction than should have been possible. One of the particularly thorny issues in program implementation is that vessels within a fishery generally differ in both the profitability and sizes of their operations. Thus, the most ineffective vessels may not be the vessels with the lowest buyout reservation prices, and it might be that highly profitable, but small, boats are bought out (since they had low total reserve prices) while large, but inefficient vessels remain. Such outcomes overpay per ton of catch-capacity removed and forfeit rents available from the transfer of catch from less efficient vessels to vessels with higher profits per unit of catch. While a few studies have explored some general theoretical properties of buyback auctions (Campbell, 1989; Weninger and McConnell, 2000; and Clark, 2005), to our knowledge, the realistic case of a fishery with an explicit focus on a heterogeneous fleet remains entirely unexamined.

As such, we develop a simple model of a buyback program implemented in a fishery comprised of vessels that differ in their skill and/or cost structures, such that the profitability of any given catch level varies across boats. Our assumption is that the fishery is subject to a TAC, closed to entry, and that the buyback program is self-financing so that those that remain in the fishery must fully cover the costs of those bought out. Equilibrium industry size under several financing and auction structures is then derived. The model is made concrete through an application based on data from the Inter-American Tropical Tuna Fishery.

The remainder of the paper is organized as follows. The next section provides a basic economic model of vessel buybacks under homogenous and heterogeneous financing systems. Section III briefly discusses the implications of the model for auction design. Section IV presents our tuna case study. Section V offers some concluding remarks.

II. The Model

In this section, we develop a simple model of a vessel buyback program in a fishery that does not have an existing rights based management system, transferrable or otherwise. The fishery operates under a cap on TAC and entry into the fishery is assumed to be restricted by those managing the fishery, such that the goal of the buyback program is to reduce the total number of vessels competing for a fixed total annual harvest.[2] Vessels are assumed to be heterogeneous in their productivity such that some are more profitable than others, i.e. vessels differ in their revenue net of operating and capital costs for any given level of catch. To avoid confusion with colloquial usage of the word productivity to refer to yields rather than efficiency, we will refer to the productivity of vessel k as its skill denoted by γ_k. Without loss of generality vessel skill is assumed to take on values between 0 and 1, with 0 representing the least skilled vessel in the fishery and 1 the most skilled. There are N boats in the fishery before the buyback program is initiated, each vessel has a unique skill level, and the distribution of skills within the fishery is known to all members. The profits earned by any boat *k* can be expressed as follows:

$$\pi_k\left(h_k, \gamma_k, \sum_{i=0}^{N} \gamma_i\right) \qquad (1).$$

Profits for boat *k* will depend on its harvest, its skill, and the skill-weighted number of boats participating in the fishery, with each term appearing in parenthesis in that order. The last term is especially important as we think about the buyback program since all boats are vying for a share of the TAC and the skill and size of the boats removed will influence the magnitude of the change in profits for those that remain. If for example, the least skilled boats caught comparatively little fish, then removing that boat will have a relatively small impact on the profits of the boats that remain since each of them can, at most, see only a small change in yield. Thus, our assumption is that vessel profits are increasing in own yield and skill and decreasing in competition for the resources, as measured by a skill-weighted fleet-size term. We further assume that the marginal impact of skill on profits is decreasing in the size of the harvest, i.e. $\frac{\partial^2 \pi_k}{\partial \gamma_k \partial h_k} < 0$. Absent this assumption, total fishery profits would always be maximized by a fishery that contains only the single most skilled fisherman catching the entire TAC.[3]

Our presumption is that all buyback programs must be self-financing, such that those that remain in the fishery must be willing and able to compensate those that have been purchased for retirement. Thus, a critical feature of our model will be the allocation of buyback payments and the financing of such payments across vessels. We begin with the simplest rule, whereby all vessels that remain in the fishery must share the costs of the buyback program equally. While this may be the easiest system to implement politically, it limits the scope for de-capitalization of the fishery since the vessels that value the buyback the most are constrained by the willingness-to-pay of the less-skilled boats that remain in the fishery. In the subsequent specification, we relax the requirement that all remaining

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[2] Clearly, a buyback program would be of little value in an open fishery, as the rents created by reducing the fleet would encourage new entrants who would then rapidly dissipate those rents. We can relax the entry constraint in a self-financing buyback program as long as all new entrants will be required to contribute to the financing of the buyback. As will become obvious from the models that we develop later in this section, new vessels will only enter if they are sufficiently high-skilled to justify buying out a lower-skilled boat in the fishery. In this case, our derived results are a lower-bound on equilibrium fleet size.

[3] One could likewise view this assumption as capturing the notion that capacity constraints prohibit one vessel from capturing the entire annual catch in the fishery.

vessels contribute equally to the buyback and focus on the aggregate rents created by the buyback. Such an approach would be politically challenging to implement and requires detailed information on boat profitability, but since boat contributions are based on increased profitability it maximizes the capital reductions attainable through a self-financed buyback scheme. In the subsequent section, we discuss the use of proxy measures for profitability under the realistic assumption that individual vessel profits are unobservable by fishery management or others in the fishery.[4]

II.A. Self-Financed Buyback Program - Homogenous Tax

In our most restrictive model, we assume that all vessels in the fishery can decide to be a buyer or seller in the buyback program and that all buyers pay an equal tax to cover the costs of retiring sellers' boats. Clearly, a vessel owner will only be willing to sell if they earn at least as much from selling as they would have if they had remained in the fishery. On the other hand, those remaining in the fishery will only be willing to pay their share of the buyout if their profits in the post-buyout fishery net of the tax are larger than what they would have earned otherwise. The structure of the buyback auction will play an important role in determining buy-out prices.

If the vessels are bought sequentially, then the lowest-skilled vessel will sell first with a reservation price equal to his/her profits when all N vessels are operating in the fishery.[5] The reservation price of the next–lowest-skilled vessel will then be based on his/her gross profits when N-1 vessels are operating in the fishery minus an equal share of the buyout price of the least skilled vessel.[6] As each vessel is removed, the profits of the remaining boats rise and thus the costs (per unit harvest) of buying out the next boat will increase. Buyouts will continue as long as the profits going to the new marginal vessel (the least skilled boat remaining after the buyout) from the buyout exceed that boat's share of the growing total buyout expense, which must be split among a shrinking cohort of remaining vessels. The equilibrium number of vessels retired will be determined by the following equation:[7]

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[4] We eschew the formal mechanism design problem when profitability is unknown. For insights into that analysis, see Deacon et al., 2012 and Groves and Ledyard, (in prep.).

[5] We assume that buyback offers are made on a price-per-ton basis, although the situation is similar if all N vessels begin with the equal sized harvests.

[6] We assume that assignment of boat index, i, is ordered such that the least skilled boat is identified by $i = 1$ and the most skilled boat by $i = N$. Additionally, we assume that each vessel has a unique skill level, and there are no ties in the ranking of boats based on skill.

[7] In the sequential buyback scheme, the reserve price (and thus the purchase price) of the 2nd least skilled vessel in the original fleet depends on the tax that boat would have to pay to fund the purchase of the least skilled boat in the fleet. Similarly, the reserve price of the 3rd least skilled boat in the fleet depends directly, via its tax term, on the buyback prices of the two least skilled vessels, and thus, also indirectly on the least skilled vessel's price through the tax term in the 2nd least skilled boat's reserve price. The careful accounting of these compounding dependencies in the tax term is not central to these models, and it is therefore omitted and assumed to be captured in the modified profit function: $\widetilde{\pi}_k\left(h_k, \gamma_k, \sum_{i=0}^{N}\gamma_i\right)$

$$\pi_j\left(h_j,\gamma_j,\sum_{i=j}^{N}\gamma_i\right)-\frac{\sum_{x=1}^{j-1}\tilde{\pi}_X\left(h_x,\gamma_x,\sum_{i=x}^{N}\gamma_i\right)}{N-(j-1)}=\pi_j\left(h_j,\gamma_j,\sum_{i=j-1}^{N}\gamma_i\right)-\frac{\sum_{x=1}^{j-2}\tilde{\pi}_X\left(h_x,\gamma_x,\sum_{i=x}^{N}\gamma_i\right)}{N-(j-2)} \quad \text{(2a).}$$

Equilibrium occurs at a fishery of size N-(j-1), where the profits to vessel j – the marginal vessel that remains in the fishery – minus his/her share of the tax required to buyout all vessels of skill γ_{j-1} or lower is equal to the profits, net of tax, j would have earned if j-1 had not retired (which correspondingly includes a term for j's share of the tax required to buyout all vessels of skill γ_{j-2} or lower). Rearranging the terms in Equation (2a) provides some additional intuition into the equilibrium conditions we have outlined. Simply put, Equation (2b) shows that under a sequential buyback program at equilibrium, the change in gross profits to the marginal boat should be equal to the change in tax-costs to that vessel.

$$\pi_j\left(h_j,\gamma_j,\sum_{i=j}^{N}\gamma_i\right)-\pi_j\left(h_j,\gamma_j,\sum_{i=j-1}^{N}\gamma_i\right)=\frac{\sum_{x=1}^{j-1}\tilde{\pi}_X\left(h_x,\gamma_x,\sum_{i=x}^{N}\gamma_i\right)}{N-(j-1)}-\frac{\sum_{x=1}^{j-2}\tilde{\pi}_X\left(h_x,\gamma_x,\sum_{i=x}^{N}\gamma_i\right)}{N-(j-2)} \quad \text{(2b).}$$

It is interesting to note, however, that if the auction can be structured such that vessels are offered a one-time take-it-leave-it (TOLI) sales contract,[8] then the equilibrium is slightly different:

$$\pi_l\left(h_l,\gamma_l,\sum_{i=l}^{N}\gamma_i\right)-\frac{\sum_{x=1}^{l-1}\pi_X\left(h_x,\gamma_x,\sum_{i=1}^{N}\gamma_i\right)}{N-(l-1)}=\pi_l\left(h_l,\gamma_l,\sum_{i=1}^{N}\gamma_i\right) \text{(3).}$$

In this case, equilibrium occurs at a fishery of size N-(l-1), where the profits to vessel l – the marginal vessel that remains in the fishery – minus his/her share of the tax required to buyout all vessels of skill γ_{l-1} or lower is equal to the profits l would have earned if no buyback program existed.[9] Two key things are different from the sequential market case. First, the cost of buying out vessels is cheaper since reservation prices for those selling are now based on pre-buyback profits for all vessels. Second, the marginal return to remaining vessels in the fishery is larger since those exiting will only be paid what they would have earned when all boats remain in the fishery. Given reasonable assumptions regarding the curvature of the profit function with respect to skill and harvest levels, the equilibrium

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[8] Technically, the TOLI offer would be a contract space with payments contingent on the number of vessels willing to sell. We will discuss this further in the subsequent section of the paper.

[9] Equation (3) also assumes that under the TOLI contract each vessel is paid his reservation price, which implies a different payment to each boat. This is straightforward in the sequential market since each vessel reveals his price through the auction. In the TOLI framework, while those vessels selling are always the least-skilled, individual vessel types must be known or a mechanism must be designed to reveal them such that each participant can be properly compensated for his/her exit.

under the TOLI arrangement characterized by (3) will lead to a larger reduction in the size of the fishery than those described under the sequential market (2).[10]

In more mathematical terms, for a given fleet size the right-hand-side of (3) is smaller than the right-hand-side of (2a), thus given the curvature of the profit function, j must be smaller than l for both equalities to hold. This implies that the TOLI contract leads to a larger capital reduction in equilibrium.

The comparison of these two cases is illustrated in Figure 1. The x-axis captures the continuum of vessels ordered by skill level and the y-axis measures profits in dollars. The figure includes a series of profit functions, denoted by $\pi_i|n$. The points on these profit functions characterize the profits of the vessel of skill i in a fishery of size n. The dotted function Π represents the profits earned by the marginal boat in a fishery after n buybacks have occurred. This function necessarily crosses the profit function for the fishery of size N-n precisely when the nth boat is the marginal vessel. In a fishery of size n=N with vessels ordered by skill, the function Π would assume the value of the profits of the lowest skilled boat. Π takes on the value of the profit of the second-lowest skilled boat when N-1 boats are in the fishery, and so forth. Thus, this function maps the value of staying in the fishery for every boat when they are the boat on the margin and corresponds to the buyout values under the sequential bidding process.

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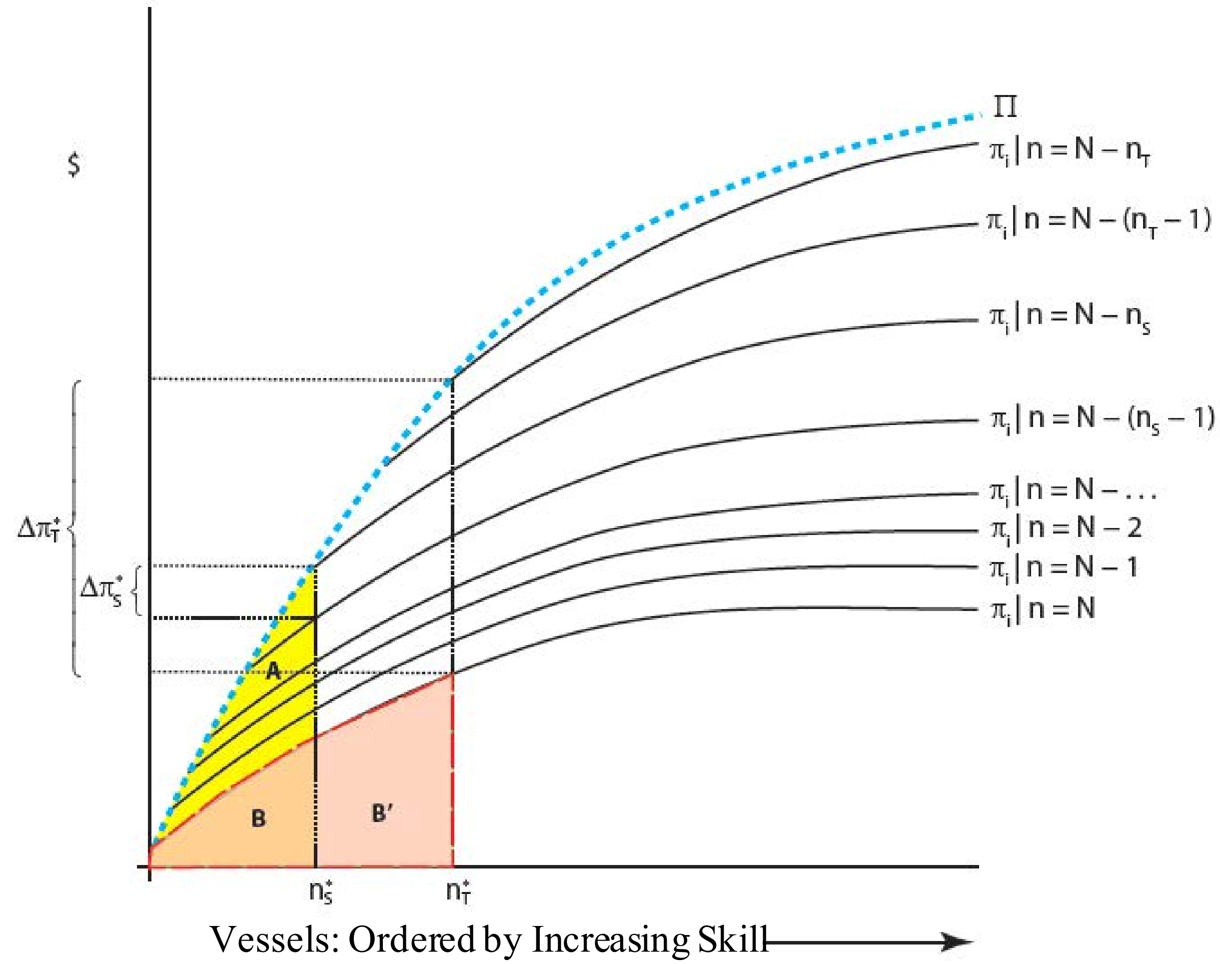
[10] Formally, this will depend on the magnitude of the elasticity of marginal profits with respect to boat skill relative to the elasticity of tax shares with respect to boat skill. If the latter, which is aggregated over many more vessels, is larger than the former then the TOLI equilibrium will generate a larger buyback.

Figure 1: Self-Financing Auction under Homogenous Tax



Looking at Equation (2b) we can see that the optimal buyback level under the sequential auction occurs where the revenue and the cost of an additional buyback are equated for the marginal vessel. We label the additional revenue available to the marginal vessel from buying out the boat immediately below it in the skill ranking as $\Delta\pi_s^*$, and denote the marginal vessel's share of the cost of this buyout as ΔT_s^*. $\Delta\pi_s^*$ is depicted in Figure 1, and ΔT_s^* can be thought of as the difference between the area A+B divided by $N - n_s^*$ and the area bounded by Π and a vertical line at $n_s^* - 1$ (not shown) divided by $N - (n_s^* - 1)$. The equilibrium buyback level under the sequential auction, denoted by n_s^* in Figure 1, occurs when $\Delta\pi_s^* = \Delta T_s^*$. A buyback of this size under a TOLI auction would only require boat n_s to pay an equal share of area B. Thus, under reasonable curvature assumptions, a TOLI market will sustain a larger equilibrium buyout, denoted by n_t^* in the figure and corresponding to the point where $\Delta\pi_t^*$ is equal to the area B+ B' divided by $N - n_t^*$.[11] Note

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[11] Under TOLI contracts, the comparison outcome for each vessel is the baseline case when no buyout takes place, and no taxes are collected. Therefore, only one side of Equation 3 includes a tax term.

that in the case of TOLI contracts, the buyout value of each boat is that boat's profit when the fleet was size N. This value is captured for each vessel by the lowest profit function in Figure 1, namely by $\pi_i|n=N$.

II.B. Self-Financed Buyback Program - Heterogeneous Tax

In the previous section, we assumed that all vessels that remained in the fishery contributed equally to the financing of the buyback program. Given the heterogeneity of skills across vessels, the benefits to each vessel that remains in the fishery are not equal. In this section, we relax the assumption of homogenous contributions to the financing of the buyback program. In particular, we assume that a buyback program is feasible as long as the aggregate rents that accrue to those that remain in the fishery are sufficient to compensate those that are bought out. The equilibrium number of vessels in this case is determined by the following equation:

$$\sum_{i=x}^{N}\pi_l\left(h_i,\gamma_i,\sum_{i=x}^{N}\gamma_i\right)-\sum_{i=1}^{x-1}\tilde{\pi}_l\left(h_i,\gamma_i,\sum_{i=1}^{x-1}\gamma_i\right)=\sum_{i=x}^{N}\pi_l\left(h_i,\gamma_i,\sum_{i=1}^{N}\gamma_i\right) \qquad \text{(4a).}$$

The equilibrium fishery size x occurs where the total profits that accrue to all vessels of quality x or higher minus the costs of sequentially buying out each vessel of quality less than x is equal to the profits that would have been earned by vessels of quality x or higher had no buyback program existed. The intuition is perhaps more straightforward after rearranging terms as follows:

$$\sum_{i=x}^{N}\pi_l\left(h_i,\gamma_i,\sum_{i=x}^{N}\gamma_i\right)-\sum_{i=x}^{N}\pi_l\left(h_i,\gamma_i,\sum_{i=1}^{N}\gamma_i\right)=\sum_{i=1}^{x-1}\tilde{\pi}_l\left(h_i,\gamma_i,\sum_{i=1}^{x-1}\gamma_i\right) \qquad \text{(4b).}$$

Here, we can see that the additional rents earned due to the buyback by those that remain in the fishery will just equal the cost of the buyback in equilibrium. If the rents were larger, more buybacks would be feasible. If the rents were lower, there would not be enough rent to justify compensating those that were bought out. Under differential contributions, the optimal fleet size will be the smallest one that delivers the TAC for which buyouts are Pareto improving. As mentioned at the outset of this section, if the highest-skilled boat had an efficiency advantage over all other boats regardless of catch size, the optimal buyback program would be one that has the best boat in the fishery buying out all others such that he/she could capture the entire TAC at the lowest cost. Under our assumption that the marginal impact of skill on profitability is decreasing in the catch, the optimal fishery size may instead occur at an interior maximum that requires *n*>1 to ensure that all vessels can be made at least as well off under the buyback program as they would have been without it.

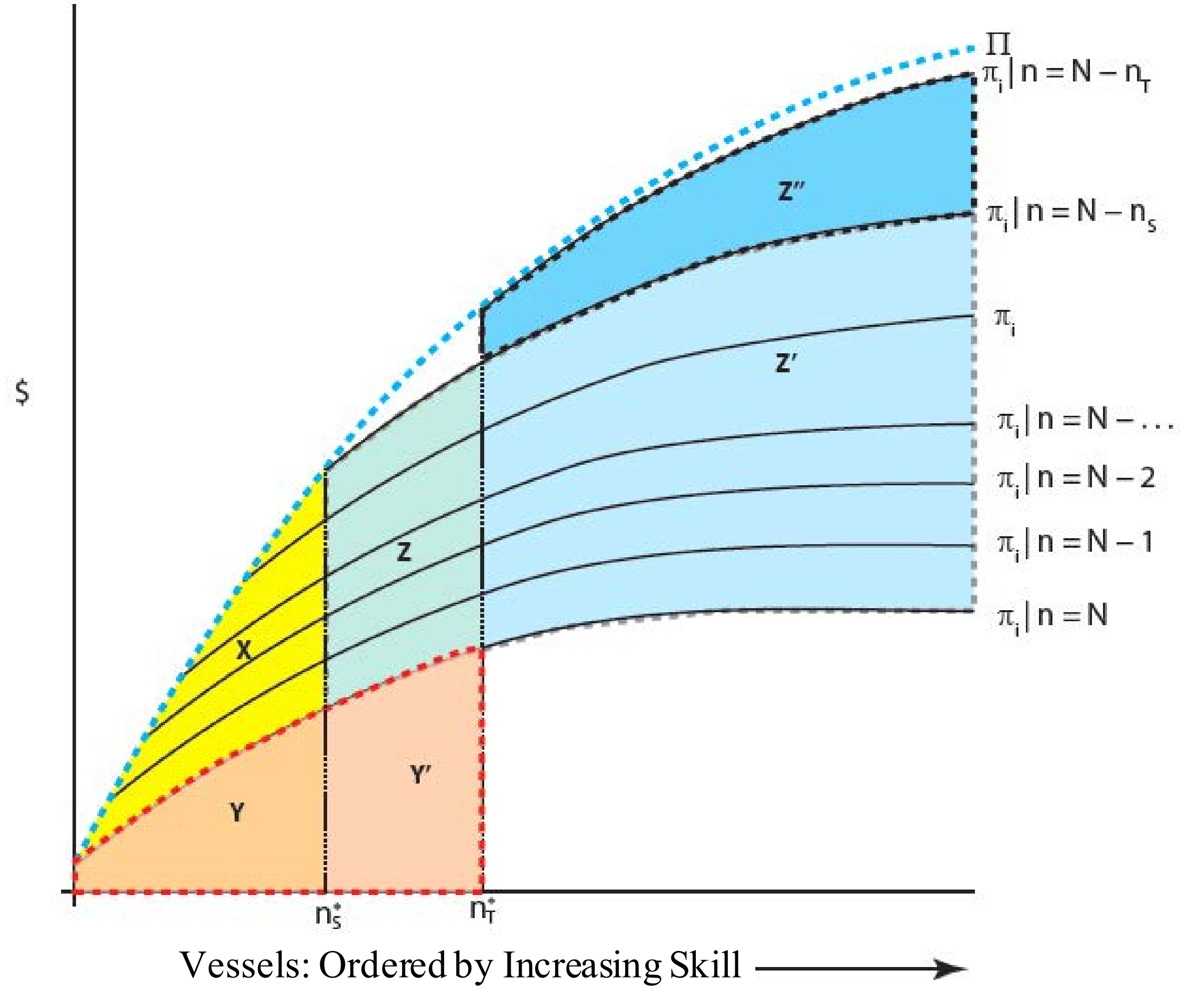
As with the earlier case, we can also explore the role of TOLI offers. In this case, reservation prices for those being bought out are referenced to the case with no buyback program. The equilibrium fishery size is determined by the following equation:

$$\sum_{i=x}^{N}\pi_l\left(h_i,\gamma_i,\sum_{i=x}^{N}\gamma_i\right)-\sum_{i=x}^{N}\pi_l\left(h_i,\gamma_i,\sum_{i=1}^{N}\gamma_i\right)=\sum_{i=1}^{x-1}\pi_l\left(h_i,\gamma_i,\sum_{i=1}^{N}\gamma_i\right) \qquad (5).$$

As before, the fact that vessels can be bought out at a lower price -- the right-hand-side of equation (5) is less than the right-hand-side in equation (4) for a given x– means that more boats will be retired in equilibrium.

The comparison of these two cases is illustrated in Figure 2. The x-axis, y-axis, and profit functions are identical to those in Figure 1. The key difference lies in the relevant margins on both the buyer and seller-side of the market. When the auction is sequential, the optimal number of vessels to buyout, n_S^*, correspond to a fishery size where the cost of the buyout, depicted by areas X+Y, is equal to the additional rents that accrue to those that remain in the fishery after the buyback takes place, depicted by the areas Z+Z'. As with the buyback comparison in Figure 1, it is readily observable that the TOLI auction will lead to a smaller equilibrium fleet size. The additional profits from the buyout at n_S^* are larger than its cost, now comprised only of area Y. The buyout will thus continue until it reaches n_t^*, where the profits generated from the buyout for those that remain in the fishery, area Z' + Z'', are just equal to the costs of the buyout, area Y+Y'.

Figure 2: Self-Financing Auction under Heterogeneous Tax



In summary, a TOLI auction with heterogeneous financing will yield the largest buyback program while a sequential auction with homogenous financing will yield the smallest. A TOLI auction with homogenous financing and a sequential auction with heterogeneous financing will yield intermediate results. Which outcome are attainable in practice will largely depend on informational constraints within the fishery.

III. Implications for Auction Design

In this section, we discuss the implications of the models developed in the previous section for the practical design of a vessel buyback auction. It is important to note that all prior analysis assumed that the distribution of vessel types within the fishery was known.[12] The

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[12] In the context of this paper, a boat's "type" encompasses its economic characteristics, including profit function and capacity.

observability of individual vessel types within that distribution is an important determinant of financing options.[13]

III.A. Financing the Auction

If individual types are not observable, a homogenous tax is the most feasible option for funding the buyback. As discussed earlier, this homogenous tax implies a self-financing buyback auction will be constrained by the benefits from reducing the size of the fishery that accrue to the marginal boat that remains within the fishery relative to his/her share of the total buyback costs. At the other extreme, if individual types are known, a heterogeneous tax that reflects the benefits that accrue to each vessel that remains in the fishery will be feasible and lead to a larger number of vessel retirements.

The implications of a heterogeneous tax when vessel types are only known imperfectly, requires formal game theoretic modeling and will depend upon the design of mechanisms that attend to the specifics of the fuzzy signal available to participants within the market. While such modeling is beyond the scope of the current paper[14], it is perhaps useful to note that one potential proxy for profitability is vessel catch. In this case, one may be able to approach the outcome where types are known, or at least improve on the outcomes under a homogenous tax, either by basing tax rates on historic vessel catch or by imposing an ex post tax on new catch rates after the buyback takes place to retroactively finance the auction.[15]

III.B. Auction Structure

Of course, the structure of bidding also plays an important role in equilibrium auction outcomes. The sequential bidding model developed earlier mirrors an open ascending price auction with an (undisclosed) price-quantity ceiling function. The ceiling delineates aggregate willingness to pay per vessel capacity removed, which increases in total capacity at a decreasing rate. The auctioneer begins with a low price and determines which boats are interested in selling. The price is then increased to determine which additional boats are willing to sell. This process continues until the price to purchase the marginal boat reaches the ceiling, which represents the most the remaining vessels are willing to pay to retire that marginal vessel. One attractive feature of this auction structure is that each person is paid based on their position in the quality ladder. Since the least profitable boat in the fleet is paid less per unit capacity than the boat of the second-lowest profitability,

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[13] Since the least profitable boats are the vessels willing to sell at the lowest price, observability is not necessary to overcome the 'lemons' problem that often characterizes markets with asymmetric information (Akerlof, 1970).

[14] See Groves and Ledyard (in prep.) for some formal modeling of this sort.

[15] Such a proxy will only work perfectly if the unobserved profitability of a vessel is linear in the catch. The intuitive scenario is that boats with larger catches have higher profitability, but it is also possible that the largest boats and most highly leveraged boats are the ones with the highest catch rates despite low profitability.

and so on, each vessel is able to extract the full rent associated with the case when they are on the margin.[16]

If buyers or sellers could organize themselves to exert market power, alternative outcomes are attainable. The take-it-or-leave-it (TOLI) market structure is one such example. The TOLI contract essentially corresponds to the case where the high-profitability boats can threaten to abandon the buyback auction, thereby compelling sellers to view their reservation prices as what they would earn when all vessels participate in the fishery. The TOLI auction structure would also set an (undisclosed) quantity-price threshold function, but would require a sealed bid descending price auction. The challenge in a TOLI market is that all but the least-profitable vessel would like to renegotiate this contract ex post. Making the threat to abandon the auction credible is also difficult on the buyer side since ex post they would be willing to pay low-quality vessels a little more to avoid this unraveling. As such, the TOLI market outcome is probably best viewed as a theoretical benchmark representing the smallest fishery possible under a revenue-neutral auction rather than an outcome that is practically attainable. Experimentation with alternative bidding structures, under varying informational assumptions, should be able to yield outcomes somewhere between sequential bidding and TOLI.

One final note on auction design also merits attention. The framework developed thus far is only voluntary insofar as vessels can choose to be a buyer or seller, but everyone is assumed to participate. One could extend this model to allow vessels to defect from the auction. In this case, the governing body of the fishery will need to partition the TAC between participants and non-participants and the uncaptured potential gain in rents forfeited via non-participation will drive down the total buyback. How large the draw down will be can be managed through a determination of the open market TAC for those not-participating in the buyback segment of the fishery.[17] Similar extensions could be made if we allowed boats to be retired from one fishery and re-deployed to another, in which case reservation prices for buyback would fall rather than rise.[18] In either case, the basic intuition of the models and auction structures to achieve them would remain largely unchanged, although the size of the equilibrium fishery would clearly differ based on how these features altered the reservation prices for sellers and the additional profits to buyers as a result of the buyback.

Clearly, which financing option is feasible and the resulting auction design that will maximize the size of the buyback will depend on a wide range of fishery-specific details. The distribution of profitability across vessels within the fishery and its observability are critical elements. In the following section, we illustrate the mechanics of a vessel buyback program through a stylized application to the Inter-American Tropical Tuna Fishery. This application is not intended to be complete nor generalizable, but rather is meant to

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[16] It is important to note that profits associated with being on the margin are likely not to match those under the firm's rent maximization scenario, but will be above the firm's profit level without the buyback.

[17] If that TAC cannot be managed then one could argue that the fishery was never subject to limited entry to begin with. As discussed earlier, buyback auctions in an open access fishery are ill-advised.

[18] See Deacon et al. (2012) for a more general model of fishery participation as a function of outside options.

highlight the required elements to design such a program and to make the insights of our model more concrete.

IV. Applications to the Inter-American Tropical Tuna Fishery

In this section we develop a series of stylized case studies to illustrate the dynamics and outcomes of buyback programs applied to a fleet of heterogeneous fishing vessels. Taking the TAC as given and assuming a strict prohibition on new entrants, we subject the fishery to three different self-financing buyback regimes and report the estimated outcomes of each regime under two distinct assumptions regarding vessel capacities. These case studies are intended to provide illustrative examples of buyback outcomes to complement the theoretical framework laid out previously and highlight the importance of differences in vessel profitability, asymmetric information, and financing structures in shaping the results of any buyback initiative. The examinations below most closely resemble the TOLI auction developed earlier and focus on the financing aspects of buyback programs under various vessel 'cost' structures.[19]

IV.A. Construction of the Synthetic Fleet

Any economic model of an active fishery must be based on accurate revenues, costs, and catch data. For the purposes of this paper, it is essential that such data captures not only aggregate, but also boat-level differences in profitability and capacity. Both data limitations and confidentiality concerns require us to construct a 'synthetic' tuna fishery based on proprietary vessel-level operational costs and catch data merged with average tuna prices for 2008-2011.

The basis of our synthetic fleet is annual catch volumes of Yellowfin, Skipjack, and Bigeye tuna for each of the 213 Class V and VI vessels that operated in the Inter-American Tropical Tuna Fishery during the period from 2008 to 2011. We sum across fish types to get a total catch for each vessel/year and use average annual price data on Yellowfin and Skipjack[20] to calculate annual revenues for each vessel. These annual catch and revenue values are averaged across years by vessel to create a representative "baseline" year for the fishery which serves as the foundation for our synthetic fleet construction. Basing the model on multi-year averages maintains important inter-vessel variation in catch and revenues while masking the identity of individual vessels and mitigating the impact that any atypical year might have on our results. The distribution of annual catch at baseline is presented in Figure 3.

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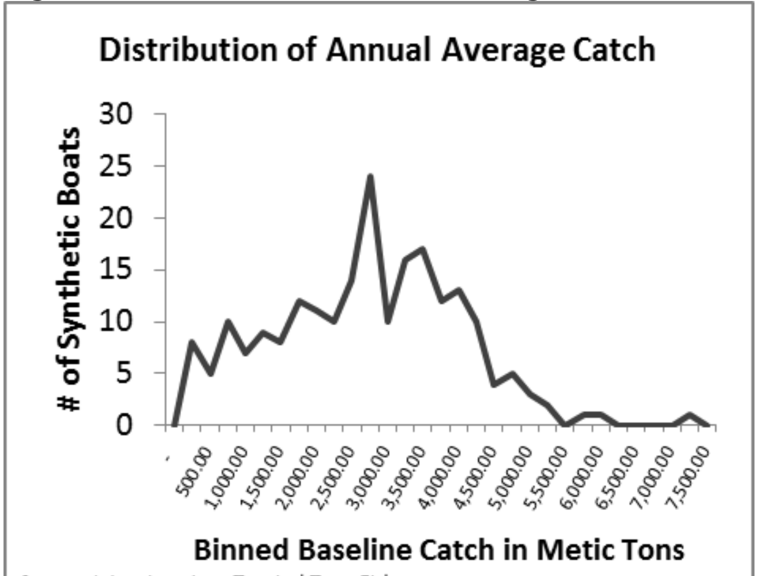
[19] For simplicity we present results from TOLI implementations only, though each buyback regime was also assessed under a sequential offer mechanism. The outcomes under sequential offers were fundamentally similar to those presented here except that lower levels of buybacks are achievable since reservation prices are larger with sequential offers. This is in line with predictions laid out in Figures 1 and 2.

[20] The Bigeye caught in this fishery are primarily juveniles and thus sell for prices comparable to Skipjack. The Bigeye catch is therefore grouped with the Skipjack catch when calculating revenues, as is common in the literature.

Figure 3: Distribution of Annual Average Catch

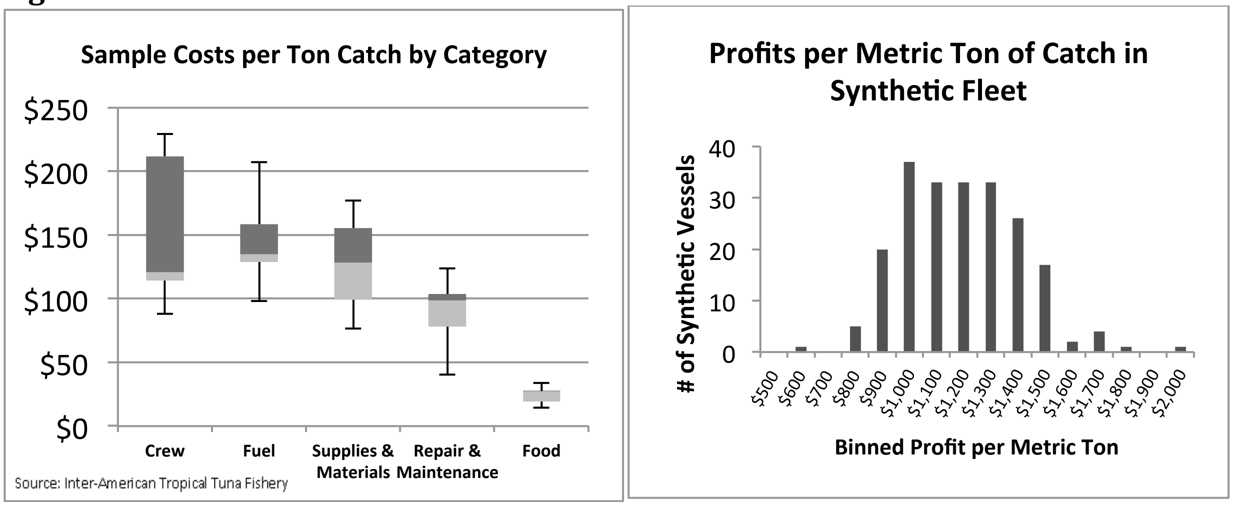


Source: Inter-American Tropical Tuna Fishery

In order to construct measures of profitability for our analysis, information on operating costs must be added to the catch and revenue data for the 213 vessels in the fleet. Data on costs is not available for all vessels and is assigned from a sample of 14 Class V and VI vessels which fished the Inter-American Tropical Tuna Fishery in the years of 2008 and 2011. This data includes costs broken down into five operational categories: Crew, Fuel, Supplies and Materials, Repair and Maintenance, and Food. Using data on catch for these vessels, we calculate costs per ton of fish caught in each category for our 14 vessel sample (see Figure 4). These figures are applied to the entire fleet by randomly assigning costs-per-ton-of-catch in the five operational categories to each vessel within the fleet. All categories of cost are summed to derive a total cost per ton of catch for each vessel in the synthetic fleet and multiplied by the vessel's total catch to calculate a total cost of operation for the baseline year.

Total profits are calculated from revenues and costs, and a profit per ton of catch is computed. Figure 4 illustrates the considerable heterogeneity in the distribution of profits per ton – a necessary condition for a successful buyback auction. We then define a vessel's "skill" in this context to be its profits per ton at baseline divided by the maximum profits per ton attained by any vessel at baseline. As described in the theory portion of this paper, such a methodology will define the skill level of the most skilled boat as unity, and all other vessels will have skill levels between zero and one.

Figure 4



IV.B. Data Limitations

Ideally we would estimate marginal cost curves for each vessel in the fleet. Such curves would capture the incremental cost of catching one more ton of fish given the level of catch already attained. In line with the assumptions on the profit function laid out earlier, we would expect the marginal cost curves to be upward sloping and convex in yield, meaning that the marginal cost of catching an additional ton of fish is rising with each ton caught, and that the magnitude of this rise is increasing as the level of catch grows. Unfortunately, due to limitations on the availability of cost data, it is infeasible to estimate full cost curves. Instead we pursue a simplification of the theoretical framework which will allow for analysis of buyback programs while placing a lower burden on our cost data. Specifically, we assume marginal costs are constant and equal to the total cost per ton assigned to each boat in our fleet. We thus assume that the cost per ton of catch is constant from the first ton caught to the last, such that total costs rise linearly in total catch at the rate of total cost per ton.

With linearly increasing total costs (paired with constant revenues per ton), the marginal impact of skill on profits is not decreasing in catch. As described in the theory section, such a framework provides no barrier to keep the most skilled boat from buying out all other vessels and assuming the entire TAC.[21] To negate this obviously impracticable outcome, we adopt vessel capacity constraints in two distinct flavors. We first run the buyout program scenarios under the assumption of a uniform vessel-per-year capacity. Next we apply the buyback programs to our synthetic fleet using individual annual vessel capacities set according to the assumption that each vessel's baseline catch is a function of its total

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[21] If the marginal impact of skill on profits is not decreasing in catch, the most-skilled vessel could pay each other vessel that vessel's marginal profit per ton for each ton of catch. By absorbing this additional catch, the most-skilled vessel would net profits per acquired ton equal to the difference between the highest profitability per ton (i.e.- that of the most-skilled boat) and the profitability per ton of the decommissioned vessels.

capacity and relative skill level. While neither approach is perfect, each serves to illustrate outcomes of buyback programs implemented under information restrictions that would likely be present in any real world implementation.

IV.C Buyback Financing Regimes

The goal of all of the buyback regimes discussed here is to maximize the number of vessels retired via the program while ensuring that the remaining boats are willing to contribute to the funding of a buyback of that size – i.e. that the auction is self-financing and incentive compatible for all boats. Under each set of capacity assumptions, three distinct financing mechanisms – the two analyzed in the theory section as well as an intermediate case – will be examined to illustrate the impact of informational constraints on buyback outcomes.

The first buyback financing regime we examine is one that assumes full information, such that buyout expenses can be redistributed amongst remaining vessels perfectly according to increased profitability. This financing rule corresponds to the heterogeneous tax scenario developed in Section II.B. While such information is unlikely to be available to a fishery manager in the real world, a fully-informed approach serves as a reasonable starting point for this examination. We will refer to this strategy as the perfect tax discrimination regime in order to distinguish it from the other heterogeneous tax regime that we will analyze.

The second regime reflects a financing structure that does not assumes perfect nor zero information regarding vessel heterogeneity, and thus should be viewed as a concrete illustration of the intermediate approaches described in Section III.A. This approach distributes the costs of the buyback among remaining vessels according to the amount of catch each vessel was able to absorb from decommissioned vessels.[22] The costs borne by vessel k under this framework, β_k, are laid out in the Equation 6, where ρ_k is equal to the amount of catch (in metric tons) which vessel k absorbs after the buyback. Note that the denominator of the function in Equation 6 is NOT equal to the total amount of catch forfeited by vessels that sell, but is instead the amount of the total forfeited catch which can be absorbed by remaining vessels. Thus Equation 6 ensures that payments made by remaining vessels cover all the costs of the buyback, while also requiring lower payments from vessels which benefit less from the buyback.

$$\beta_k = \frac{\rho_k}{\sum_{j=1}^{N} \rho_j} \quad (6).$$

In a sense, this regime mirrors the perfect tax discrimination regime, except that increased catch is used to proxy for increased profits when distributing costs. In this case, only vessel baseline catch and total capacities are needed for collection of payments. It is also

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[22] In all cases, catch volume under the TAC that is "freed up" through the decommissioning of vessels is distributed equally to all remaining vessels as long as they have available capacity to absorb the additional volume.

noteworthy that such an approach is conceptually similar to imposing an ex post tax on catch increases after the buyback takes place to retroactively finance the auction.[23]

The last buyback financing approach uses the homogeneous tax described in Section II.A. Collection of equal contributions from each boat that is not retired in the buyback requires only information on which vessels sold at what prices, and which chose not to sell under the buyback program, and importantly does not require information on vessel type or profitability. Thus, this most simple cost dispersion scheme has the lowest information requirement for the regulatory authority.

In the following section, these three buyback finance regimes will be assessed first under uniform capacity constraints and then under the assumption of heterogeneous capacity constraints based on vessel skill level. In all cases, taxes collected from remaining boats must cover the total purchase price of vessels that sell under the buyback program, total harvest is not allowed to exceed the baseline harvest levels, and catch from decommissioned vessels is allocated equally (up to capacity constraints) among remaining boats.

IV.D. Case Study Results

For analytic simplicity, we will treat the buyback programs that follow as if all transactions occur on an annual basis. Results for a permanent buyback based on the present discounted value of future income changes would be identical as long as all agents share the same discount rate.[24] We begin by assuming that all vessels within the fleet have a fixed and uniform annual capacity constraint. In particular, we examine auction outcomes for three distinct capacity levels: 7500 metric tons per year, 8500 metric tons per year, and 9500 metric tons per year. The smallest of these numbers was chosen to correspond roughly to largest catch by any vessel in our dataset. The others are meant to illustrate the sensitivity of buyback outcomes to the degree to which vessel capacity constraints are binding.

Table 1 describes our results and several features are noteworthy. First, even the least productive buyback generates a sizable de-capitalization of the fishery – 110 vessels retired in an initial fishery of 213. The most productive program would buyout 167 vessels and scale the size of the fishery back by 75 percent. This result reflects the wide variation in profitability across the existing fleet and the rents created when more profitable vessels absorb the catch of many of the least profitable ones. Second, as predicted by our theory, the perfect tax discriminating finance regime leads to the largest buyback program, the homogenous finance regime leads to the smallest, and the heterogeneous finance regime generates buybacks that lie in the middle. Lastly, a comparison across panels in Table 1 suggests that the wedge between the different financing regimes shrinks as capacity grows.

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[23] In fact, if the tax rate assigned to each vessel is set equal to that vessel's profitability on the absorbed catch, this approach becomes exactly the perfect tax discrimination regime.

[24] Alternatively, the results presented here can be interpreted as those from an annual program where some vessels pay others not to participate in the upcoming year.

While the difference in the size of the buyback between the perfect tax discrimination regime and the homogenous regime under a capacity constraint of 7500 MT is nearly 30 percent, this difference shrinks to 12 percent under a constraint of 9500 MT. Since the homogenous tax regime is limited by the equal assignment of costs, even amongst high-skilled boats that will gain relatively little under the buyback due to capacity constraints, relaxing that requirement allows relatively more boats to participate.

Table 1: Buyback Outcomes under Uniform Capacity Constraints

	Uniform Capacity	Boats Bought-Out
Perfect Tax Discrimination	7,500 MT	154
Heterogeneous Tax – Based on Catch		149
Homogeneous Tax		110
Perfect Tax Discrimination	8,500 MT	161
Heterogeneous Tax – Based on Catch		157
Homogeneous Tax		126
Perfect Tax Discrimination	9,500 MT	167
Heterogeneous Tax – Based on Catch		164
Homogeneous Tax		147

The results in Table 1 were based on the simplifying assumption of uniform capacity constraints for all vessels in the fleet. While this is convenient, it is unlikely that the vessel which catches the smallest amount at baseline (only 7 metric tons in our synthetic fleet) has the same total capacity as the vessel which catches the largest amount (>7,000 metric tons in our case). We now turn our attention to results under more nuanced capacity constraint assumptions.

In order to define a capacity constraint for each vessel in the fleet, we assume that at baseline, the Most Skilled Vessel (MSV) in the fleet is operating at some factor of its total capacity. We then assume that less skilled vessels are operating at a fraction below that factor equal to the inverse of their skill. This relationship is set out explicitly in Equation 7 below:

$$C_k = \bar{h}_k * \frac{1}{SF} * \frac{1}{\gamma_k} \quad (7)$$

Where $\bar{h}_k$ is the baseline harvest of vessel k, SF is the scale factor share of capacity at which the MSV is operating at baseline, and γ_k is the skill level of vessel k.[25] Thus, the share of a vessel's capacity it is assumed to be using at baseline depends on the vessel's baseline catch, the scale factor, and the vessel's relative skill level.

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[25] Remember that the skill level of each boat is equal to that vessel's profits per ton of catch at baseline divided by the profits per ton of the MSV at baseline. Thus, we have $\gamma_{MSV} = 1$.

Outcomes from our three buyback regimes under the relative capacity constraints are presented in Table 2 for scale factors equal to 80%, 90%, and 100%. Because the use of relative capacity constraints effectively reduces the excess capacity of most vessels in the fleet compared to uniform capacities,[26] the number of vessels by which the fleet can be reduced under any buyback regime without violating incentive compatibility is lower under relative capacity constraints. In particular, the perfect tax discrimination regime yields somewhere between 85 and 110 retired vessels. As with the uniform capacity constraint, the heterogeneous tax regime performs almost as well, leading to retirements of between 79 and 105 vessels. The largest differences arise under the homogenous tax regime, under which virtually no vessels are retired. These results are due to a single vessel in our fleet with an exceptionally small baseline catch, and very high estimated skill level. Even under the most generous assumptions regarding relative total capacities, the entire fleet is constrained because this small boat can never absorb more than five additional tons of catch from decommissioned vessels. It is noteworthy that even when we drop the three high-skilled boats with the lowest capacities, the buyout only climbs to 11 vessels retired under the homogenous tax with an 80% scaling factor (results not reported).

Table 2: Buyback Outcomes under Relative Capacity Constraints

	Capacity Scaling Factor	Boats Bought-Out
Perfect Tax Discrimination	80%	110
Heterogeneous Tax – Based on Catch		105
Homogeneous Tax		2
Perfect Tax Discrimination	90%	98
Heterogeneous Tax – Based on Catch		93
Homogeneous Tax		1
Perfect Tax Discrimination	100%	85
Heterogeneous Tax – Based on Catch		79
Homogeneous Tax		0

While data limitations and the parsimony of our economic models suggest that the case study results should be interpreted carefully, several important insights can be gleaned from them. First, while perfect knowledge of vessel level profitability yields the largest

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[26] The uniform capacities assigned to all boats had to be greater than the largest baseline catch, therefore most boats were modeled as having large amounts of excess capacity in the baseline case under the uniform capacity constraints approach.

buyback, a program based largely on historic catch and vessel capacity can perform nearly as well. Second, buyback regimes implemented on a heterogeneous fleet with insufficient vessel-level knowledge - and thus requiring a homogenous financing rule - will generate significantly smaller buybacks and sometimes zero capital reductions in the fishery. Lastly, the assumptions regarding available capacity significantly impact outcomes, and the amount of catch which remaining vessels can absorb is the critical feature which defines how many boats can be removed from a fishery via buyback. The analog to this finding in a more generalized setting (which includes our theoretical framework) is that outcomes are highly sensitive to the slopes and concavity of vessel costs and thereby profit functions. Thus, the degree to which financing regimes that rely on intermediate measures of vessel-level profitability – such as our tax based on catch – deliver buyback outcomes similar to the perfect price discriminating tax will depend on how well such proxies track the actual changes in vessel profitability.

This insight reinforces the merits of our decision to avoid estimation of vessel cost curves with our limited data, as any results from such an approach would likely be uninformative.

V. Conclusions

The collapse and near collapse of several important global fisheries has underscored the importance of management schemes that limit the overexploitation of fishery resources. While economists have generally advocated tradable property rights schemes as a solution, most fisheries have eschewed the assignment of formal property rights in favor of limited entry policies. While such policies can limit resource overexploitation, they do little to address overcapitalization since vessels within the fishery continue to compete against one another to capture more of the finite stock. This 'race to fish' is inefficient as it can shrink fishing seasons and erode fishery-wide profits, and might well enable and incentivize violation of catch restrictions.

In this paper, we developed a simple theoretical model of vessel buyback auctions to address issues of overcapacity and excess capitalization. Within a closed fishery with a fixed TAC, we examine equilibrium buyback outcomes under a variety of assumptions. Our comparison of sequential versus TOLI auctions mirror open-ascending and closed-descending price auctions frequently employed in other market settings and illustrate some important difference in the level of de-capitalization attainable. Alternative assumptions regarding the distribution of costs under a self-financing buyback also significantly impact auction outcomes. As these financing schemes vary in their vessel-level informational requirements, their examination has important implications for the implementation of any actual buyback program. Our theoretical modeling is followed by a stylized case study inspired by the Inter-American Tropical Tuna Fishery, which suggests that a wide range of auction structures could roughly half the size of the existing fleet. It also makes the dramatic point that information poor settings can entirely derail a buyback.

While the results from our analysis highlight the potential role for buyback programs, several limitations merit careful attention. First, the theoretical model and its application assume that a vessel voluntarily participates as either a seller or buyer in the auction whenever its profits are expected to be non-negatively impacted by the buyout, but do not account for voluntary non-participation based on any other rationale. The possibility of non-participation is both real and raises the prospects for strategic interactions that could greatly complicate equilibrium outcomes. The implications of such interactions necessitate the development of a more formal and game theoretic model of vessel behavior. Second, our analysis presumed the ability to limit entry into the fishery. It is important to note that even if total capacity can be limited initially, a successful buyback auction will increase the profitability of the fishery and thus make entry and capital stuffing by vessels already in the fishery even more attractive. Should the ability to limit entry be eroded over time, the achieved de-capitalization will be ephemeral and create dynamic disincentives for participation in future auctions. Lastly, our case study was based on a 'synthetic' fleet under some strong assumptions. It was meant to be illustrative and should not be considered to mirror any real world scenario. It nevertheless highlighted the practical challenges in determining vessel willingness to pay to contribute to a buyout due to the complicated interaction between cost structures and vessel capacity. More research is needed to understand this relationship and how it varies across different settings. Together, these issues comprise a future research agenda.

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