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MARKET DESIGN FOR FISHERY IFQ PROGRAMS

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Abstract

I examine the impact of market design on the performance of a cap-and-trade program for Individual Fishing Quotas. In equilibrium, neither the term of the quota, the number of years for which it is valid, nor the method of initial allocation, granting or selling, has a differential effect on the protability of the shery or the quality of the environment. However, the term of the quota and the method of initialization can have a big impact on the price discovery process and whether equilibrium is attained. Because of this, both the fishery and the environment can be signicantly better off with a mixture of historically based grants and auctions with some form of limited term quotas. I also discuss some additional benefits from an initialization process that generates some revenue for the public. Section 5 contains a summary.

Keywords: Market Design, Individual Fishing Quotas, Term Quotas, Auctions

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1 Introduction

A Cap-and-Trade program with Individual Fishing Tradable Quotas (IFQs) is an efficient and cost-effective method for managing a fishery. Once IFQs are created and allocated, the total catch is controlled through the cap. This control provides benefits both to fishermen, who care about the economic viability of the fishery, and to environmentalists, who care about the biological viability of the fishery. The benefits to the environment come in a more sustainable fish population. The benefits to the fishermen come in the increase in profits due to solving their commons problem. In many respects, the interests of the fishermen and those of the environmentalists are aligned.

There are many choices that must be made when a new IFQ program is initiated. Two of these fall under the purview of market design: the structure of the quota, the quota that is created to control the catch, and the method by which the initial allocation of quotas is made. Both of these choices potentially affect the economics of the fishery and the sustainability of the environment. In this paper, I look at limited term quotas as an alternative to permanent quotas. I also evaluate the differential effects on fishery and environment of an initial grant of quotas versus an initial sale.

The findings are straight-forward if sometimes counterintuitive. (1) In equilibrium, neither the term structure of the quotas nor the method of initial allocation affect the profitability of the fishery or the sustainability of the environment. All choices of the fishermen (effort, gear choice, entry or exit, etc.) are the same in all variations. (2) The structure of the quotas and the method of initial allocation can affect the extent to which market equilibrium is attained. Some limited term structure on the quotas and some auctioning will lead to more transparent and liquid trading which in turn will lead to higher profitability for the fishermen and a higher value for the environment. This does require some of the potential increase in wealth to be allocated to the operation of the program, but all will be better off if that is done. (3) Even if the IFQ program is run in a way that attains its highest level of performance for both the fishery and the environment, there remain opportunities for further improvement. If some of the wealth created by the IFQ program is put towards solving these problems, both the fishery and the environment can be made better off together.

The rest of this paper is organized as follows. In Section 2, I present a model of the fishery that includes both economic and environmental components. I analyze the equilibrium impact of two methods of initial allocation:

granting and selling. I also analyze the equilibrium impact of limited term quotas. The material in this section is somewhat technical. The reader who wants to avoid that can jump straight to Section 2.5 for a non-technical discussion of the model and results. In Section 3, I look at the price discovery process - how the market equilibrium of Section 2 might be attained. I look at the impact of grandfathering, auctioning, and limited terms in this context. In Section 4, I look at some of the remaining economic and environmental problems that are not solved by an IFQ program even if it functions at full efficiency. A summary with conclusions is provided Section 5.

2 Equilibrium Analysis

I begin with a fairly standard model of the fishery.[1] I try to capture both the economic and environmental aspects of the situation.

The fishery The stock of fish in year t is b_t. The annual rate of change of this stock is given by:

$$b_{t+1} = b_t + f(b_t, e_t) - Q_t \tag{1}$$

where e_t is the quality of the environment, including the carrying capacity, and Q_t is the total catch that period. $f(b_t, e_t)/b_t$ is the natural growth rate of the population. The exact form of f will be different for different species, but the market design results in this paper do not change if f changes.

The environment The environment can replenish itself if left alone but can also be damaged if fishermen use inappropriate technology or participate in extensive discarding.[2] There are I fishermen labeled $i = 1, ..., I$. Let τ^i be the level of technology used by fisherman i, how they fish, where higher values of τ^i are good for the environment but cost the fisherman more to

[1]Equations (1) and (3) can be found in early models of the fishery. More recent references include [4] and [5]. Equation (2) is one of many ways of getting the externality to the environment into the model. The results in this paper do not depend on this particular form.

[2]By environment I generally mean habitat quality, those things that provide the carrying capacity for the biomass in equation (1).

execute.[3] The annual rate of improvement (or decline) in the environment is given by

$$e_{t+1} = e_t + g(e_t, \tau_1, ..., \tau_I). \tag{2}$$

It should be noted that the form of (2) provides a commons problem that an IFQ program does not directly solve. That is, a fisherman's choice of the way they fish affects all of the fishermen in the fishery. Choosing a good method conveys benefits to all but, in choosing one's methods of fishing, one generally considers only the benefits to oneself. Thus fishermen will generally choose too little of the good method. We will return to this issue in Section 4.

The fishermen The final piece of the model is the profit, π^i, of a fisherman in any one year. I assume that[4]

$$\pi^i = pQ^i - c^i(Q^i, \tau^i, b_t). \tag{3}$$

Fishermen may differ in their type of equipment, boat size, capabilities, marginal value of leisure, outside opportunities, etc. In this model they are not homogeneous.[5]

2.1 An IFQ program

A tradable IFQ program is implemented by choosing a maximum limit on the total catch in each year, called the total available catch (TAC), and then allocating a percentage of the quota to each fisherman. Let α^i be the percent

[3] It is assumed here that the choice of technology can be made anew in each period with no switching costs. This is undoubtedly unrealistic, but it only strengthens our conclusions. If desired, transition costs and irreversible effects could be added at a cost of complexity.

[4] I write this in the standard way, assuming perfect competition in the output market with the competitive price of p. This is not necessary for the conclusions of the paper. The results would still obtain if p depended on Q, as it would in an non-competitive marketplace. The results would also still obtain if demand can shift over time. For sake of simplicity, I leave out all of these complexities.

[5] If all fishermen are homogeneous, then the problem is really trivial. Allocate the quota evenly among them. There will be no need for trading. The results to follow still hold and are significantly easier to obtain.

of the the TAC that fisherman i is allocated where $\sum_i \alpha^i = 1$. If the TAC in year t is A_t then he can catch a maximum of $\alpha^i A_t$ fish in that year.

Accompanying the allocation is a policy to choose the TAC for each year t, indicated by A_t. That policy is given by

$$A_t = A(b_t, e_t). \tag{4}$$

Here I am assuming that the TAC is set each year in a way that depends predictably on the biomass b_t and the environmental quality, e_t. This does not require that biomass or environmental quality be predictable. The equation subsumes a lot of processes whose specific forms are not necessary for this paper. For example, the stock assessment part of determining the TAC is included in equation (4). It is required that each fisherman's catch in year t, Q_t^i, be no greater than their quota for that year which is α^i times the TAC.

For this paper, I will assume that all fishermen always use all of their quota. That is,[6]

$$Q_t^i = \alpha^i A(b_t, e_t). \tag{5}$$

I assume there is a sufficiently accurate monitoring and strong penalty system in place to deter over-running one's quota.

Summary Given a fishery policy, determined by (4) and (5), and a quota allocation, α^i, a fisherman at time t will choose an amount of catch Q_t^i and a method of fishing τ_t^i. This in turn will determine the next period's stock of fish and environmental quality through equations (1) and (2). This process repeats itself into the future.

2.2 Permanent Quota

The purpose of this paper is to evaluate the effect of two market design alternatives on the choices of fishermen and, thus, on the biomass and environmental quality. I begin the comparative analysis by considering a base case on which I can build. I begin with the case in which fishermen have an allocation of permanent quota.

[6] The only time this will not be true is if the TAC is not binding on the fleet; that is, there was no need for a quota. Otherwise, if there is trading, any fisherman with excess quota will sell it to another.

The situation is made a bit more complex than the standard model because of the availabilty of trading at every point in time. At the beginning of each period t, a fisherman holds an amount of quota α_{t-1}. In period t, they can buy or sell quota which will determine how large their catch can be, they must choose their technology, how they fish, and they must do this taking into account the future. We model this as follows.

Suppose there are going to be a series of spot markets, one for each t, in which fishermen can buy and sell quota at that time. It is easiest to see what happens in such a setup by considering a Rational Expectations Equilibrium.[7] In the Rational Expectations Equilibrium model, there is a price q_t, for quota bought or sold in time t. The price q_t clears the market for quota in period t. Finally, at any time t^*, the price at t is correctly anticipated by all fishermen for all times $t \geq t^*$.

At time t, a fisherman owns an amount of quota, α_{t-1}, carried over from the previous period. She needs to choose, for each t, a level of desired quotas for t, α_t, and a level of technology for t, τ_t She faces a dynamic programming problem where the solution is found recursively by solving for all $t \geq 0$:[8]

$$\begin{aligned} v_t(\alpha_{t-1}, b_t, e_t) = &\max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t(\alpha - \alpha_{t-1}) \\ &+\delta v_{t+1}(\alpha, b_{t+1}, e_{t+1})\}. \end{aligned} \tag{6}$$

On the left hand side of the equality is the present discounted value to the fisherman of holding α_{t-1} when the biomass is b_t and the state of the environment is e_t. On the right hand side are her revenue in this period minus her costs in this period minus her financial costs of trading plus the discounted value of where she ends up at the end of t (which is the beginning of $t + 1$). The values of b_{t+1} and e_{t+1} come from equations (1) and (2). She has two choices to make in each t: how much to fish, α_t, and how to fish, τ_t.

We can greatly simplify the equations to make it easier to derive some results. Let

$$W_t(\alpha_{t-1}, b_t, e_t) = v_t(\alpha_{t-1}, b_t, e_t) - q_t\alpha_{t-1}. \tag{7}$$

[7] There are many ways to model a complete set of markets, including allowing a full set of futures markets at each time t for both leases and quota. One can also introduce uncertainty about prices, etc. But these generalizations mostly introduce unnecessary complexities into the analysis.

[8] I leave off the index i from expressions when it is clear what is going on to avoid excessive notation.

I can then re-write (6) as

$$W_t(\alpha_{t-1}, b_t, e_t) + q_t\alpha_{t-1} = \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t(\alpha - \alpha_{t-1}) + \delta[W_{t+1}(\alpha, b_{t+1}, e_{t+1}) + q_{t+1}\alpha]\}$$

or in more compact form, subtracting $q_t\alpha_{t-1}$ from each side

$$W_t(\alpha_{t-1}, b_t, e_t) = \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t\alpha + \delta q_{t+1}\alpha + \delta W_{t+1}(\alpha, b_{t+1}, e_{t+1})\}. \tag{8}$$

It is straight-forward to verify that $\partial W_t/\partial\alpha_{t-1} = 0$ for all t, so we can write W_t as $W_t(b_t, e_t)$. We can come to a number of conclusions about the choices of the fishermen from this.

First, the choice of quota, α_t, solves

$$\max_{\alpha}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau_t, b_t, e_t) - (q_t - \delta q_{t+1})\alpha\}. \tag{9}$$

and is entirely independent of the value of α_{t-1}. That is, in a fully functioning marketplace, the optimal choice by a fisherman of quotas needed in any period does not depend on their previous period holdings. Further, in a fully functioning market, the fisherman's choice of α_t is entirely independent of the future value to the fisherman. The value $W_{t+1}(b_{t+1}, e_{t+1})$ does not show up in equation (9). The only future thing that is important in the choice of α is the price for quota in $t+1$, q_{t+1}. If markets are working correctly then $q_t - \delta q_{t+1}$ is just the leasing price for 1 year for 1 unit of quota - the price to buy 1 unit less the discounted price from selling it in the next period.[9]

Second, the choice of technology, τ_t, solves[10]

$$\max_{\tau}\{-c(\alpha_t A(b_t, e_t), \tau, b_t, e_t) + \delta W_{t+1}(b_t + f(b_t, e_t) - A(b_t, e_t), e_t + g(e_t, (\tau_1, ..., \tau_I/\tau))\} \tag{10}$$

[9] If the leasing price were higher than this, one would be better off buying and re-selling than leasing. The opposite would be true if the leasing price were smaller than this. This is the natural result in liquid and transparent markets where all buyers and sellers have access to frictionless capital markets. That is, they can easily borrow or lend money. This is undoubtedly not true in reality which creates market frictions. I will address these frictions later.

[10] I use the standard notation $(\tau_1, ..., \tau_I/\tau)$ to represent the vector $(\tau_1, ..., \tau_I)$ with the ith entry replaced by τ. I am assuming a Nash Equilibrium in τ.

This choice is also independent of α_{t-1}. It does depend on the future, through $W_{t+1}(b_{t+1}, e_{t+1})$. It does not depend directly on the price of quota although it does depend on the choice of α_t which does.

Equations (9) and (10) determine a demand function for α_t^i, independent of α_{t-1}, where

$$\alpha_t^i = \alpha_t^i(b_t, e_t, q_t - \delta q_{t+1}). \tag{11}$$

These demands determine an equilibrium set of prices $\hat{q}_1, \hat{q}_2, ..., \hat{q}_t, ...$ where

$$\sum_i \alpha_t^i(b_b, e_t, \hat{q}_t - \delta \hat{q}_{t+1}) = 1, \text{ for all } t. \tag{12}$$

If the fishery is in a steady state then $b_t = b, e_t = e, \tau_t^i = \tau^i$ and $q_t = q$ for all t. So, in particular, if $\delta = 1/(1 + r)$ where r is the interest rate, then at time t the lease price of quota $(\hat{q}_t - \delta \hat{q}_{t+1}) = [r/(1 + r)]q$.

I have not explicitly let the fisherman contemplate the possibility of exit from or entry into the fishery. To do so would not change any of the comparative results, but would only further complicate the notation. I do show in the Appendix how to include entry and exit in the model.

2.3 The Effect of the Process of Initial Allocation under Permanent Quota

In this section, I look at the effect of two initial allocation schemes: granting and selling. An example of a grant is grandfathering which involves a one-time allocation based on historical performance in the fishery. An example of a sale is auctioning, a one-time sale of quotas. I do this in the context of permanent quota with full trading in fully functioning markets.

2.3.1 Grant

Suppose the IFQ program is initiated with a one time grant of permanent quota to each fisherman. At time 0, each fisherman is given a gift of α_0^i of the quota where $\sum \alpha_0^i = 1$. For now, it is not particularly important how this allocation is determined, just that it is free.[11] From the preceding analysis, the value to i of α_0^i is found in equation (6), where $v_1^i(\alpha_0^i, b_1, e_1)$. This can also

[11] If it is known or anticipated that grandfathering is the way that the initial allocation of the quota is to be done, then a very bad unintended consequence occurs. Fishermen find

be written as in equation (7) and following: $W_1^i(b_1, e_1) + q_1\alpha_0$. In equilibrium the marginal value of α is simply, q_1, the price at which this quota could be sold in period 1. Alternatively, it is the value to the fisherman of not having to buy α in period 1. So if the fisherman is granted an amount α_0, at $t = 1$ that gift is worth $q_1\alpha_0$ to him. If, on the other hand, he buys α_0 at a price q_0, then at $t = 1$ it is worth $(q_1 - q_0)\alpha_0$ to him.

In a fully functioning market equilibrium, the present discounted value of the quota program is the value of the grant. It is entirely capitalized in the initial price, q_1.

2.3.2 Sale

Suppose the IFQ program is initiated with a one time sale of permanent quota to each fisherman. There are many ways to implement such a sale. Here, I assume it to be done with a uniform price clock auction.[12] Although the proceeds from the sale can be distributed in many ways through many processes, including ones which involve participation of the fishermen themselves, I will assume for now that the proceeds go to the public, to be distributed later.

Invoking the revelation principle from mechanism design, it is easy to show that, with liquid and transparent markets, the allocation and price outcome of the sale with a uniform price clock auction will be the same as that of a demand-supply market.[13] If q^A is the price per unit quota that must be paid at the auction at the beginning of period 1, then at that price, fisherman i will want to buy the amount of quota $\hat{\alpha}^i(q)$ that solves (from (9)):

$$\max_{\alpha}\{p\alpha A(b_1, e_1) - c(\alpha A(b_1, e_1), \tau_1, b_1, e_1) - (q^A - \delta q_2)\alpha\}. \tag{13}$$

The solution to this problem is exactly the same for every q^A as the solution to (9). How much quota a fisherman starts with has no bearing on how

it now in their interest to to focus their investments and efforts on things that raise their catch levels so as to, hopefully, increase their share of quota at the time it is allocated. Over-fishing can be significantly increased in anticipation of the quota and can actually lead to a lower stock for a long period of time, even after the IFQ program begins. For the rest of this paper, I will ignore this effect.

[12]What is crucial here is that it is a one-price equilibrium. For the curious, I describe the uniform price clock auction in more detail in Appendix III

[13]See [2] for more on the theoretical and experimental background for this claim of equivalence.

much quota he wants to end up with.[14] It follows that the auction price will be exactly the same as the equilibrium price, $\hat{q}$, that solved (12). That is, $q^A = q_1$. The price paid in the auction is exactly the same as the price that would arise in period 1 if the quota were granted and then trade occured. Further, even if trading were to be opened after the auction, none would occur since the auction already has allocated the quota to those who value it the most.

The value to i of the sale is $W_1^i(b_1, e_1)$ since $\alpha_0 = 0$.

2.3.3 Comparing Grant and Sale

Because the optimal decisions for the fishermen in each period are independent of their quota holdings in previous periods, the comparison between grants and sales at $t = 0$ is straight-forward. All choices, those of (α_t, τ_t) for all t, are the same whether there is an sale or grant. This means that $W_1^i(b_1, e_1)$ is the same in both cases. The only difference is in the distribution of the present discounted value of the quota program capitalized in the price, q_1. Under the grant, the fishermen get q_1, the public gets 0. . Under the sale, the public gets q_1, the fishermen get 0.[15] The value at time 1 to our fisherman of the quota, α_0, is $v_1(\alpha_0, b_1, e_1) = W_1(b_1, e_1) + q_1\alpha_0$. He is better off with the gift by an amount $q_0\alpha_0$. We can summarize this in

Theorem 1 *With permanent quota and fully functioning markets, in equilibrium, the path over time of Q_t, b_t, and e_t will be exactly the same under a regime in which quota is granted as under a regime in which quota is sold. Quota prices will also be the same under either regime. Under the grant the fishermen capture the full value, q_1, of the quota program. Under the sale the public captures the full value, q_1 of the quota program.*

As before, efficiency and environmental impact are the same under grant and sale. Only the distribution of wealth differs.

[14] In a well-functioning market without frictions, the opportunity cost of using his holdings is exactly the same as his cost of buying quota in the market place.

[15] Actually, the fishermen also get something else under both grant and sale - $W_1(b_1, e_1)$. This will be higher than what they would have had without a quota program. So the fishermen receive some benefit from the program, under any initial allocation process.

2.4 Quota with Limited Terms

It is not necessary to make an all or nothing decision with respect to the initial allocation of the quota. One does not need to choose between granting all of the quota in period 1 or selling all of the quota in period 1. There are policies that avoid either the outright gift of all value to the incumbents, through a grant of permanent quota, or the outright grant of all value to the public, through the sale of permanent quota. One such approach is to grant quota with a limited term. Under this policy one allocates quota originally, as in a grant, but makes the original quota good only for T years. At the end of the Tth year, those quotas are no longer valid and new ones, which are now permanent, are then sold.

In this section, I look at the impact of a policy of limited term quota and how this compares with a grant or sale of permanent quota at time 0. I work backwards for three periods because the answer reveals itself at that point.

Grant of Permanent Quota Remember how the problem looks at time T-1, T, and T+1 to someone who received permanent quota in period 0. At the beginning of year T+1, a fisherman's value is (I use the superscript G to denote that this is the grant solution):

$$W^G_{T+1}(b_{T+1}, e_{T+1}) + q^G_{T+1}\alpha_T \tag{14}$$

Moving back to T, we know that

$$\begin{aligned} W^G_T(b_T, e_T) + q^G_T \alpha_{T-1} = \max_{\alpha,\tau}\{ & p\alpha A(b_T, e_T) - c(\alpha A(b_T, e_T), \tau, b_T, e_T) \\ & - q^G_T(\alpha - \alpha_{T-1}) + \delta[W^G_{T+1}(b_{T+1}, e_{T+1}) + q^G_{T+1}\alpha]\}. \end{aligned} \tag{15}$$

Finally, for T-1, we know that

$$\begin{aligned} W^G_{T-1}(b_{T-1}, e_{T-1}) + q^G_{T-1}\alpha_{T-2} = & \max_{\alpha,\tau}\{p\alpha A(b_{T-1}, e_{T-1}) \\ & - c(\alpha A(b_{T-1}, e_{T-1}), \tau, b_{T-1}, e_{T-1}) - q^G_{T-1}(\alpha - \alpha_{T-2}) \\ & + \delta[W^G_T(b_T, e_T) + q^G_T \alpha]\}. \end{aligned} \tag{16}$$

Grant of Limited Term quota followed by Sale of Permanent Quota Now let's consider someone who receives the same amount of quota in period 0 but where that quota expires at the end of period T. To continue fishing after T, they will have to buy newly available permanent quota from the sale between T and $T+1$.

At time $T+1$ the difference between the fisherman who receives a permanent quota at time 0 and the fisherman whose quota lasts only T years is minimal. For the fisherman with the limited term quota, their value at T is (using the superscript L to denote the limited term solution):

$$W^L_{T+1}(b_{T+1}, e_{T+1}) = W^G_{T+1}(b_{T+1}, e_{T+1}) \tag{17}$$

Compare this to (14) for the person with permanent quota. Looking forward, the value to both is the same. The only difference at $T+1$ is that the fixed term quota holder loses the value of α_T.

But this loss carries back to T. In period T, the value of the limited term quota holder is:

$$\begin{aligned} W^L_T(b_T, e_T) + q^L_T \alpha_{T-1} =& \max_{\alpha,\tau}\{p\alpha A(b_T, e_T) - c(\alpha A(b_T, e_T), \tau, b_T, e_T) \\ & -q^L_T(\alpha - \alpha_{T-1}) + \delta W^L_{T+1}(b_{T+1}, e_{T+1})\} \end{aligned} \tag{18}$$

Because the scenarios are different and, thus, the equilibrium prices could be different, we use q^L. Suppose $q^L_T = q^G_T - \delta q^G_{T+1}$. Then I can re-write (18) as

$$\begin{aligned} W^L_T(b_T, e_T) + q^G_T \alpha_{T-1} =& \max_{\alpha,\tau}\{p\alpha A(b_T, e_T) - c(\alpha, A(b_T, e_T), \tau, b_T, e_T) \\ & -q^G_T(\alpha - \alpha_{T-1}) + \delta[W^G_{T+1}(b_{T+1}, e_{T+1}) + q^G_{T+1}\alpha]\} \end{aligned} \tag{19}$$

Comparing this to (15) we can see that the optimal choices for α_T and τ_T are exactly the same in G and L. It follows that $W^L_T(b,e) = W^G_T(b,e)$.

To see that this is not all an accident, let us move back one more period to $T-1$ where the value for the limited term is:

$$\begin{aligned} W^L_{T-1}(b_{T-1}, e_{T-1}) + q^L_{T-1}\alpha_{T-2} =& \max_{\alpha,\tau}\{p\alpha A(b_{T-1}, e_{T-1}) \\ -c(\alpha, A(b_{T-1}, e_{T-1}), \tau, b_{T-1}, e_{T-1}) &- q^L_{T-1}(\alpha - \alpha_{T-2}) \\ & +\delta[W^L_T(b_T, e_T) + q^L_T\alpha]\} \end{aligned} \tag{20}$$

Because $W^L_T(b,e) = W^G_T(b,e)$, if I let $q^L_{T-1} = q^G_{T-1} - \delta^2 q^G_{T+1}$, then I can rewrite (20) as

$$\begin{aligned} W^L_{T-1}(b_{T-1}, e_{T-1}) + q^G_{T-1}\alpha_{T-2} =& \max_{\alpha_{T-1},\tau}\{p\alpha A(b_{T-1}, e_{T-1}) \\ -c(\alpha A(b_{T-1}, e_{T-1}), \tau, b_{T-1}, e_{T-1}) &- q^G_{T-1}(\alpha - \alpha_{T-2}) \\ & +\delta[W^G_T(b_T, e_T) + q^G_T\alpha]\} \end{aligned} \tag{21}$$

Again it is true that for these prices, that the optimal choices for α_{T-1} and τ_{T-1} are the same in both G and L and $W^L_{T-1}(b,e) = W^G_{T-1}(b,e)$.

I can continue this back to $t = 0$. In the end what we learn is

Theorem 2 *Let q^G_t be the equilibrium prices and α^G_t, τ^G_t be the equilibrium choices when permanent quotas are granted at $t = 0$. Define the prices $q^L_t = q^G_t$ for all $t > T$ and $q^L_t = q^G_t - \delta^{T+1-t} q^G_{T+1}$ for all $t \leq T$. Then the prices q^L_t are equilibrium prices for the limited term quota policy. Further, let $\alpha^L_t = \alpha^G_t$ and $\tau^L_t = \tau^G_t$. Then α^L_t and τ^L_t are equilibrium choices for the limited term quota policy.*

Behavior is exactly the same under a grant of permanent quota or a grant of limited term quota followed by an auction. It relatively easy to understand intuitively what is happening. All holders of the quotas at T suffer a loss of $q_{T+1}\alpha^i_T$ when their quota expires. In equilibrium, the price of the quota α_t is adjusted in each period t up to T for the present discounted value of this coming capital loss. The present discounted value at time t of this per-unit loss in period $T+1$ is $\delta^{T+1-t} q_{T+1}$. The loss is capitalized into the price of the quota.

The effect of the limited term policy is simply a lump-sum transfer out of the system at time T. But it also shares the benefits of the quota program. The fishermen get $q_1 - \delta^{T+1-t} q_{T+1}$. The public gets $\delta^{T+1-t} q_{T+1}$.

Sale of Permanent Quota at $T = 0$ To finish this section, let us compare the grant of limited term quota with the sale of permanent quota at T = 0. Remember that, from Section 2.3.3, the difference between the grant and the sale of permanent quota at $T = 0$, is that under the grant the fishermen get q_1 more and the public gets q_1 less than under the sale. Now consider the grant of quota with life T followed by the sale of permanent quota. From the previous section, the value at t = 0 to the fishermen of the difference between this and a grant of permanent quota is $\delta^{T+1} q_{T+1}$.

If T = 0, then, the value of the difference at $t = 1$ is δq_1, exactly the same as the sale of permanent quota at 0. The difference to the fishermen between a sale at 0 and a sale at T is $q_1 - \delta^{T+1} q_{T+1}$. If the fishery were in a steady-state situation, then $q_t = q^*$ for all t and the difference to the fishermen is $(1 - \delta^{T+1})$, the amount they gain by postponing the transfer of wealth from period 0 to period T.

A Mixed Bag One can accommodate into our analysis any number of term lengths and any variety of grant and sale. For example, suppose one wants to allocate 78% of the quota through grandfathering with 22% to be allocated by auctions over the next 10 years. The management could reserve 2% for an initial auction. the rest, 20%, would be allocated to the fishermen. Each fisherman would be given a portfolio of quotas that consists of 10% of 1 year quotas, 10% of 2 year quotas, and so on up to 10 year quotas. This would mean that the management would have 2% of the original quota to sell at auction for each of the next 10 years. When sold at auction, the quotas would be permanent. As before, nothing changes in the equilibrium choices of the amount of fishing, α_t or the style of fishing, τ_t. The market prices of quota will be different to reflect the flow out of the system of the proceeds from each of the 10 auctions.[16] If the prices of quota would be q_t^E under a grant of permanent quota, then we can determine the price of quota at t with a remaining life of L as $q_t^E - \delta^{L+1} q_{t+L+1}^E$. The present discounted value of the auction proceeds will be $S = (.02)[q_1 + \delta q_2 + ... + \delta^{10} q_{11}]$. So the public gets S and the fishermen get $q_1 - S$.

Adaptive Management A proposal exists in the West Coast Fisheries to hold back 10% of the quota to be used to solve various social and environmental side effects of the fishery. One idea is that each year, 10% of the quota for that year, would be sold to generate a flow of income for the program. In a fully functioning marketplace, the sale of 10% of quota in year t is equivalent to leasing the quota for 1 year. The leasing price is $q_t - \delta q_{t+1}$. Thus, the sale will yield $I_t = .1(q_t - \delta q_{t+1})$. The present discounted value of this is $.1(\delta^{t-1} I_t) = .1(\delta^{t-1} q_t - \delta^t q_{t+1})$. Adding these up over time gives us the present discounted value of the leases which is $\sum_{t=0}^{\infty} I_t = .1q_1.$, the discounted value of the 10% of the grant of quota for adaptive management. The fishermen get $.9q_1$ and the public gets $.1q_1$.

2.5 Summary

In this section, I have provided a fairly standard equilibrium model of the fishery that includes its effect on the environment. In the model, fishermen are heterogeneous with possibly different costs of fishing, labor-leisure pref-

[16] There will also be more markets since the price of quota with 2 years left will be different from the price of quota with 3 years left.

erences, size of boat, etc. They choose the level at which they fish: the size of the catch. They also choose how they fish, the technology they use: gear choice, location, high-grading, etc. A simple cap-and-trade IFQ program is included in the model. If there are well-functioning, transparent and liquid markets for the quota quotas, then a Rational Expectations Equilibrium will occur. So I look at what happens in this equilibrium.[17] In the context of this model, I analyze two fundamental features of the market design for an IFQ program: the initialization process and the term of the quotas. I evaluate three policies of initialization and term: the grant of permanent quota, the sale of permanent quota, and the grant of limited term quota followed by a sale of permanent quota. The results are very easy to state. In equilibrium, the behavior of the fishermen, with respect to both the level of fishing and the method of fishing is no different under any of the three policies. Therefore, the effect of the policies on the fishery and the environment is identical. Only the distribution of wealth is different.

These conclusions are also true for any combination of limited term quota, sales, or grants. That means that it is possible to fix the amount and timing of any split between the fishermen and the auctioneer by choosing the appropriate initialization policy. I give one example above under "a mixed bag".

3 Getting to Equilibrium

An IFQ program that hands out quotas and does nothing further leaves a lot of important problems unsolved. One of these is incomplete trading. If a cap-and-trade IFQ program is to attain its full potential for profitability and environmental health, the cap is not enough. There must be trade. All the possible gains from trade must be found and captured.[18] Indeed, market equilibrium will not be found without this; in equilibrium, there are no more gains from trade. But equilibrium does not happen magically. Getting there requires a well-functioning, transparent, and liquid market place.

[17] In the next section, I take up what happens if markets have significant frictions and are neither transparent nor liquid.

[18] There are gains from trade if at least two people can gain from reallocating quota between them. That is, if A can make more profit with the quota than B, then the quota can be transferred to A and A can compensate B in a way that makes them both better off. Such a trade is voluntary and improves the welfare of both.

In this section, I explore the impact of the quota structure and the initialization policies on the process of getting to equilibrium, a process often referred to as price discovery. We will see that in disequilibrium, as opposed to equilibrium, market design does matter.[19]

Grants and laissez faire Consider an initialization policy in which a permanent quota is granted based on historical performance with trade presumed to follow. For now, let us assume that nothing else is done as part of the IFQ program. In particular, there are no organized markets or brokers. I refer to this situation as "laissez faire" since traders are on their own to find counter parties willing to trade with them. Will the level of trade necessary for efficient utilization of the fishery, higher profits, and better environmental health naturally occur? Unfortunately the answer seems to be that it is not likely. Let us examine why.

With the traders on their own, this is a market place that is fraught with frictions. The only way a trade can occur is if two fishermen put in the effort to search, find each other, and negotiate a trade. Search costs interfere with the finding process and asymmetric information interferes with the negotiation process. Together, these frictions will prevent fishermen from taking advantage of much of the potential gains from trade.[20] Each individual knows only about their own little piece of the marketplace. They know nothing of other negotiations and other trades. There is little transparency. Consequently there will be only sporadic trades. There is little liquidity.

Forget for a moment the process of finding one another. Consider the negotiation process where there is bilateral asymmetric information. Neither fisherman knows for sure the price at which the other is willing to buy or sell and each would like to make the best possible deal. It has been well understood since 1983.[21] that the incentives created by asymmetric information lead bidders to shade their bids when involved in bilateral negotiations. Even if there are gains to be had, there is a significant probability that trade will not occur. So, even if all possible pairs of fishermen meet and negotiate, an

[19]Because the state of economic modeling of price discovery is significantly poorer than of equilibrium, I will rely on intuitive arguments in this section. Much of what I will say can be supported with economic theory and experiments. We are working on those now.

[20]These frictions are sometimes called transactions costs and are well recognized for inhibiting trade in other cap-and-trade programs, such as those for air pollution control. See [6].

[21]See [3] for a full explication of this theoretical result.

unlikely occurrence, many of those gains from trade will still be foregone. But that fact, in turn, reduces the intensity with which they will search. Since the expected gains from search are reduced by the negotiation frictions, the return to searching is reduced. Lower returns means fewer will search.

An initialization policy of granting with a laissez faire approach to trading is not enough. Asymmetric information and search costs impose significant frictions and prevent traders from finding and sharing the gains from trade. The market place lacks transparency and liquidity. Incomplete trading is the result. The potential profits achievable with complete trading will not materialize.

3.1 Can brokers help?

The naturally occurring response to search and negotiation frictions is brokers. Indeed, some argue that brokers are the complete solution to the inefficiency of bilateral trading. The argument is that the broker is a central clearing house for information about all possible trades: who the buyers and sellers are and the prices at which they are willing to transact. With that information, the broker can facilitate all trades and ensure complete processing of all gains from trade.

But there are at least two problems with this argument. First, brokers cannot by themselves mitigate the asymmetric information problems. Just as a seller knows that she can gain by not revealing the true price at which she is willing to sell to a buyer, she can gain by not revealing the true price at which she is willing to sell to a broker. The reason is not complicated and is a variation of the revelation principle. Basically, it is in the interest of the broker to complete trades. If the seller were to tell the broker her true willingness to sell and a buyer were to, instead, tell the broker a lower willingness to buy than is truly the case, then even if the broker treated them fairly and priced the transaction halfway between the two offers, the seller would lose out since the price would be closer to her true willingness to accept than to the buyer's true willingness to pay. The seller avoids this by increasing her report to the broker. Second, brokers are not altruists: they do this for the income and they get income by charging commissions on trades. Those commissions further lead to incomplete trading for the same reason any transactions costs do. Brokers may reduce search costs but they impose costs of their own.

Although brokers won't solve the asymmetric information problems, they could provide information about who is proposing a trade and at what prices trades are occurring. But, a single broker would not reveal this information, unless required to by the individuals managing the IFQ system. If there are multiple brokers, or easy entry into the broker business, competitive pressures will force the information out. But most cap-and-trade programs do not have the volume of trading required to support many brokers. For example, in the RECLAIM program market of Los Angeles for pollution control, there is a single broker handling most trades. Price information is secret, as are the size and composition of most trades. Thus transparency is not realized. It is not in the nature of naturally occurring brokers to create transparency.

Relying on naturally occurring brokers is not enough. Although search costs are reduced, asymmetric information and broker's fees continue to impose significant frictions and prevent traders from finding and sharing the gains from trade. The market place still lacks transparency and liquidity. Incomplete trading is the result. The potential profits achievable with complete trading will not materialize.

3.2 Improving transparency

It is possible to improve transparency for traders of IFQs. But it does require proactive work on the part of the management of the IFQ program. A simple improvement over laissez faire would be to require publication in an easily accessible place of the prices and fees involved in all trades. But that is not enough. That only provides information about past trades. Traders also need information about possible future trades. An alternative that provides such information is a central market site, such as a web-based marketplace. With modern information technology, it is really easy and fairly inexpensive to set up and manage such a market. It is also possible to do this in a way that is simple for people to understand and use. At such a website, fishermen could easily see current bids and offers as well as historical information on prices and quantities of previous trades. They could also easily make bids or offers and complete profitable trades.[22]

Creating transparency is desirable, easy, and inexpensive. But is it enough? If there is sufficient liquidity, then the answer is yes. Liquidity mitigates the asymmetric information problem through competition. Holding out for a

[22] A by-product of such a market is that, through the clearance and settlement process, a very current and precise database of ownership of all quota can be easily maintained. More on this later.

better trade is less likely to work if others can jump in and replace you. Therefore, a trader's bid will be closer to his true willingness to trade.[23]

Unfortunately in most cap-and-trade programs, liquidity is very low. In cap-and-trade markets there are relatively few external events which can cause a significant shift in the value to the quota, the tradable quota. Thus, as opposed to equity markets, a trader, who constantly monitors the quota marketplace in search of capital gains from price movements can anticipate only low returns. Since the costs of paying constant attention are very high, traders will only occasionally and intermittently check the market for information on market history and for possible trades. This aggravates the liquidity problem. In such a situation, individuals who do want to buy or sell will only post their bids or offers for a short time.[24] Bids and offers will not be posted often, and when they are posted they will not be viewed often. It will require a lot of luck for a buyer who is only posting a bid for a short time to meet a seller who is only occasionally monitoring the market. And, even if they happen to meet online, it is highly likely they will be the only buyer and seller at that time which means that the bilateral asymmetric information problem is back again.

Creating transparency by providing a web based marketplace is not enough. Asymmetric information and costs of attention will lead to low liquidity. Without both transparency and liquidity, trading will be incomplete. The promise of the cap-and-trade IFQ program will not be achieved.

3.3 Improving liquidity

It is possible to improve liquidity for traders of IFQs. But it does require proactive work on the part of the management of the IFQ program. The key to getting sufficient liquidity is to recognize that the market need not be completely liquid all the time. In a cap-and-trade marketplace, where events that cause significant value changes rarely happen, to accomplish the price discovery necessary for the attainment of equilibrium and to capture all of

[23]The theoretical basis for this can be found in [1]. There is also ample experimental evidence that it doesn't take many participants to eliminate the adverse selection problem. Sometimes just two or three on each side is enough.

[24]If I do not constantly monitor my offer, I risk the possibility that I may lose potential capital gains. Something might cause the quota value to increase by a lot and, if someone else knows that before I do, they might accept my offer before I had a chance to raise it. They will resell and achieve the capital gains that I missed through my inattention.

the gains from trade, it is sufficient to ensure that liquidity is high for only a small number of brief times each year. But, during those times, traders must be serious and something must happen. If not, then in the future these liquidity moments will just disappear.

The best way to guarantee active liquidity moments is with auctions that require the attention of all incumbents in the IFQ program. Well-designed auctions provide very efficient price discovery. And they are very transparent. An excellent example of an auction that would improve liquidity in a cap-and-trade program is the uniform price, clock auction.[25] Such auctions can be two-sided with both buyers and sellers bidding. If everyone actively participates in such an auction, good things happen. At the end of the auction, those buyers who value the IFQs the most will have received them. Those sellers with the lowest value for the IFQs will have sold them. And since this is a uniform price auction, every transaction is at the same price. This means there is no need for further trading after the auction stops. The auction exhausts all gains from trade and the efficient allocation is found. The price discovery process has found the equilibrium price and allocation.

One of the assumptions above was that everyone actively participates. How can we guarantee participation by all incumbents? It is not enough to just announce an auction. Participation occurs only if one feels that they have something at stake. There may be those who, correctly or not, assume they have little to gain from participation and so they don't even pay attention. For example, if buyers think few sellers will participate then the buyers may not bother. This has the force of a self-fulfilling prophecy. If buyers don't show then seller won't. How do we avoid this? If the auctioneer has quota that will be put up for sale at any price then buyers will show. That in turn will lead sellers to show.

How does the auctioneer get the quota to sell? Through the initialization policy. As I summarized in section 2.5, it is possible to implement any combination of grant and auction without affecting, in equilibrium, either the profitability of the fishery or the health of the environment. So it is certainly possible to design an initialization policy that provides some quota at points in time when liquidity events are desired.

An initialization policy which combines granting some portion of the quota directly to the fishermen and selling the rest in strategically timed auctions is enough. Grants provide some guarantee that incumbent fish-

[25] I describe the design of this auction in some detail in Appendix III.

ermen will not be seriously hurt with the introduction of a cap-and-trade IFQ program. Auctions will provide the means to create the liquidity and transparency so vital to the full realization of the potential of the program. There may be resistance to this since, according to the analysis in Section 2, it involves a transfer of wealth from the fishermen to the public. But the increase in profit that will occur because of the increase in transparency and liquidity should more than pay for the initial loss of quota. The net effect is that all fishermen will be better off.

A regular series of uniform price clock auctions with the required participation of all owners of quotas will improve the liquidity. This leads to complete trading with all gains from trade realized. The quota to be auctioned can be planned with a complete initialization policy. Since the gains from these trades are sufficient to fund the auctions and still leave incumbents protected, all can be better off with this policy. The promise of the cap-and-trade IFQ program can be achieved.

3.4 Summary

To fully attain the promise of an IFQ cap-and-trade program, trading must occur in a way that exhausts all potential gains from trade. This requires a transparent and liquid marketplace. Under a policy in which a grant of permanent quota is made and nothing further is done, there will be significant search and negotiation frictions. The naturally occurring market place will be neither naturally transparent nor liquid.

The management of the IFQ program must be more proactive. Policies which require public posting of all trading information can increase transparency somewhat but only with lags so that the information is not as relevant as it should be. The operation of a simple web based market can significantly improve the transparency and relevance of information in the marketplace. But that market will still be illiquid.

With a web based market place and regularly scheduled uniform price clock auctions with full articulation, an IFQ cap-and-trade program can achieve a high level of fishery profits and environmental health.

3.5 An Application: Overfished Species

One place where the issue of getting to equilibrium is particularly crucial is in new IFQ programs in species that are seriously overfished. Here the initial TAC is going to be very small. It is highly unlikely that allocating on the basis of historical catch will leave anyone with sufficient quota to make fishing profitable.[26] A lot of buying and selling will be necessary to have the quota used in the most efficient manner. If there are only brokers without the transparency or liquidity of markets, gross misallocations will result.

This is a situation that calls for a program of mixed grants and auctions. Some grants based on historical catch can provide some support for the incumbent fishermen, even if they sell their quota and exit. Auctions can provide a clear and transparent signal as to the clearing price for quota. Initial auctions can also be designed so that those fishermen with granted quota who want to sell can participate and be sure that they will receive a fair price. Fishermen who want to buy quota will also be able to do so in a way that does not take advantage of them. The auction provides a level playing field and a transparent and liquid method for getting the limited quota into the hands of those that can best use it. All others profit somewhat by that sales.

4 Other Opportunities

If the IFQ program decides, as it should, to implement an initialization program that provides for regularly scheduled auctions, then there is a question as to what to do with the revenue from such auctions. It could be given to the incumbents but that would ignore a number of opportunities where its use could either further increase the efficiency of the fishery or the fairness of the final benefits created by the IFQ program. In this section, I provide some examples of those opportunities.

4.1 Other Commons Problems

An IFQ program solves the commons problem of over-fishing of target populations. The reduction in the number of fish caught leads to increases in biomass overtime which leads to a reduction in the costs of fishing. The total net present discounted value of profits in this fishery go up. This increase is shared by all fishermen in this fishery. But the benefit to any one fisherman is less than the costs to that fisherman if he were to unilaterally cut back. Thus, it is only through the collective action implementation of an IFQ

[26] It will also be very contentious since there is so little to go around.

program that the net gains can be realized. But over-fishing is not the only commons problem of the fishery. There are other dimensions where collective action can improve both the profitability of the fishery and the health of the environment. In this section I look briefly at a few of these.

Management and Operation To achieve a significant increase in profitability for a fishery by the implementation of an IFQ system requires two things: good management and good markets. Without either of these, the potential gains will be seriously dissipated. Neither is naturally provided. The reason is obvious - there is a free rider problem. I would rather have others pay for this than me, since I will get the benefit anyway. The implementation of an IFQ program is a recognition that sometimes group agreement on a quota can make everyone better off. Funding and supporting good management and markets is another examples where this can happen

We have seen that to get good markets one needs an active web based marketplace and regularly scheduled auctions of existing quota. This requires funds. It is also important to have good management. Some organization must be in place to monitor and measure each fisherman's catch. Then that catch must be compared to the IFQs owned by that fisherman to assess compliance. To do that, ownership of the IFQs must be tracked and recorded, much as is done with title to real property.

Good management also requires cash to pay for the needed personnel and processes. With good management and markets, profits will be high. Without good management, all of the profits and biological gains of an IFQ program will eventually be eroded away by the same forces that required the creation of the program in the first place. It is not unreasonable to take some of the gains to create the gain. The higher profitability from good management and good markets can be self-supporting and leave fishermen and the environment better off than under a grant of permanent quota and a laissez faire marketplace.

By-catch There are also problems that affect fishermen outside a particular fishery, particularly by-catch. Some reduction in unintended by-catch may occur with the reduction in effort that occurs with IFQs. In many current U.S. fisheries, a target fishery can be shut down when the by-catch becomes excessive, the by-catch of one fisherman now affects all. This is another commons problem that can be addressed by the use of market methods. The standard command and control approach is to allocate portions of a total allowable bycatch amount and/or put in place more monitoring and enforcement penalties. Some of the revenue from the auctions could certainly justifiably be used to support monitoring or enforcement. But there is a better way.

A more incentive compatible approach would expand the IFQ program to multiple species. Those who trawl species beyond their permitted types or levels would then have to buy IFQs of the type they caught. The market approaches using the cap and trade auctions and fixed term methods as described in this paper can be applied directly and similarly to the management of by-catch. This provides both a natural form of compensation to the fishermen of the by-catch species as well as an incentive to find and adopt avoidance methods against further by-catch. In this process a separate or integrated market is created as well as spot trading with similar characteristics of transparency and liquidity as described.

4.2 Transitional Fairness

With the introduction of an IFQ program, the increase in economic efficiency from reducing the commons incentives means that, in the aggregate, the system is better off. Total profits will be higher. But, there will be winners and losers. The increase in efficiency means that winners should be able to compensate the losers. After the compensation everyone is better off than without the IFQ program. One justification for an initialization program which grants a significant amount of the quota on an historical basis is the protection of the incumbents who lose in the reorganization that follow the beginning of the IFQ program. The argument is simple. The grandfathering of quota in proportion to past fishing history means that each fisherman's allocation is roughly about what their quota would be under a command-and-control system with no IFQs and no trading. Therefore, all incumbents can continue fishing at that level and be no worse off than they would be under command-and-control. But they can do much better by trading and, since trading is voluntary, anyone who trades will be better off including those that leave the industry. They were potential losers under the IFQ program but they are compensated with their grant of initial quota.

But usually the mechanism for providing the compensation to anyone who is not an incumbent fisherman is not included as part of an IFQ program. Those who are uncompensated losers often includes the communities and businesses that have supported the inefficiently high level of fishing activity in the past. With the IFQ program their income will drop. It is not unreasonable to allocate some of the funds from the regularly scheduled auctions to help compensate those hurt by the increase in efficiency.

There can also be those who, while they are ultimately winners, face temporary transitional difficulties as the fishery and others who rely on it shift to different, and usually lower, levels of economic activity. Some use of auction revenues could help make the distribution of final winners more fair.

5 Summary

I have considered several aspects of market design for fishery IFQ programs. In particular I have looked at the implications for fishery profitability and environmental health of alternative initialization policies and of the term of the quotas.

In Section 2, I focus on market equilibrium. I have provided a fairly standard equilibrium model of the fishery that includes its effect on the environment. In the model, fishermen are heterogeneous with possibly different costs of fishing, labor-leisure preferences, size of boat, etc. They choose the level at which they fish: the size of the catch. They also choose the technology they use: gear choice, location, high-grading, etc. A simple cap-and-trade IFQ program is included in the model. If there are well-functioning, transparent and liquid markets for the quota quotas, then a rational expectations equilibrium will occur. So I look at what happens in this equilibrium. I evaluate three policies of initialization and term: the grant of permanent quota, the sale of permanent quota, and the grant of limited term quota followed by a sale of permanent quota. The results are very easy to state. In equilibrium, the behavior of the fishermen, with respect to both the level of fishing and the method of fishing is no different under any of the three policies. Therefore, the effect of the policies on the fishery and the environment is identical. Only the distribution is different.

These conclusions are also true for any combination of limited term quota, sales, or grants. That means that it is possible to fix the amount and timing of any split between the fishermen and the auctioneer by choosing the appropriate initialization policy.

In section 3, I look at price discovery, the process of finding equilibrium. To fully attain the promise of an IFQ cap-and-trade program, trading must occur in a way that exhausts all potential gains from trade. This requires a transparent and liquid marketplace. Under a policy in which a grant of permanent quota is made and nothing further is done, there will be significant search and negotiation frictions. The naturally occurring market place will be neither naturally transparent nor liquid. The management of the IFQ program must be more proactive. Policies which require public posting of all trading information can increase transparency somewhat but only with lags so that the information is not as relevant as it should be. The operation of a simple web based market can significantly improve the transparency and relevance of information in the marketplace. But that market will still be illiquid.

Regularly scheduled uniform price clock auctions with the required participation of all owners of quotas will improve the liquidity. They lead to complete trading with all gains from trade realized. The quota to be auctioned can be planned with a complete initialization policy without affecting the equilibrium fishing or environmental choices. Since the gains from these trades are sufficient to fund the auctions and still leave incumbents protected, all can be better off with this policy. The promise of the cap-and-trade IFQ program can be achieved.

The revenue generated by regularly scheduled auctions provides an opportunity to solve other commons and fairness problems in the fishery. In Section 4, I discuss these very briefly. The commons problems are management, gear switching, high-grading, and by-catch. The fairness problems are compensation for losers outside of the fishery incumbents and for those bearing unusual transition costs.

6 Recommendation

Full realization of all the potential benefits from an IFQ program require both the cap and the trade. The cap comes with the IFQ program. The trade depends on market design. My recommendations are to develop an initialization policy which is a mixture of grandfathering and auctions. The revenue from the auctions can be used for a number of programs that would be of benefit to all in the fishery: good management with strong enforcement, accurate record keeping, well run auctions, good markets with a web based marketplace, subsidies for gear switching, and minimizing high-grading, and a strong by-catch program.

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Appendix I: Other Initialization Policies

It is not necessary to choose between granting all quota with permanent terms, selling all quota with permanent terms, or granting all quota for a limited term and then selling it at the expiration of the term. It is possible to mix granting and selling in any proportion desired. It is also possible to mix terms. Examples of alternatives to either fully grandfathering or fully auctioning are easy to find.

Overlapping term quotas Issue quotas of 10 years in length with differing start dates. In year 1 there would be 10 tranches of quotas. One tranche would have a life of 1 year, one would have a life of 2 years, etc. Each incumbent would get their grandfathered share of each of these tranches. When each tranche expired it would revert to the Management who would then auction it off. This would generate a cash flow of approximately 10% of the total available in each of the first 10 years.

Annual auctions Grant all of the quotas initially. Each year, 5% percent of each person's holdings as of December 31 would revert to the management to be auctioned off in, say, January.[27] One has to be careful with this type of scheme since it would be easy for enough to be transferred from fishermen to management so that the value to the fishermen of the quota at time 0 could be negative. If x% is taken each year then the value in year 0 of the amount taken in year t is $x\delta^{t+1}q_{t+1}$. So the present discounted value of taking x% each year is $x\sum_{t=1}^{\infty}\delta^t q_t$. In steady state, this is $xq/(1-\delta)$. So if $x > (1-\delta)$ then the value of the quota at time 0 to the fishermen will be negative.[28] If this were the case, they would certainly be loathe to participate.

There are many variations of these schemes. Which is preferred depends on the desired timing and amounts of the cash flow between the initial holders of the quotas and the Management.

[27]One could also do 2.5% on each of June 30 and December 31.

[28]Usually the relationship between the discount rate δ and the interest rate r is $\delta = 1/(1+r)$, so $(1-\delta = r/(1+r)$. If the interest rate is 5% then x would have to be less than about 4.75% in order for this program to leave the fishermen with a positive valuation of quota at time 0.

Appendix II: Entry and Exit

Adding in the possibility for a fisherman to enter or exit does not change any of the conclusions on differential impact in this paper. To see that remember equation (6).

$$v_t(\alpha_{t-1}, b_t, e_t) = \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t(\alpha - \alpha_{t-1}) + \delta v_{t+1}(\alpha, b_{t+1}, e_{t+1})\}.$$

Suppose that the fisherman can choose once to exit, sell his boat and equipment, and sell any quota he may have. When would he do that and how would that affect the decisions? We rewrite (6) to

$$v_t(\alpha_{t-1}, b_t, e_t) = \max\{K_t + q_t\alpha_{t-1}, \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t(\alpha - \alpha_{t-1}) + \delta v_{t+1}(\alpha, b_{t+1}, e_{t+1})\}\} \tag{22}$$

where K is the market value of his boat and equipment at this time. This leads to the equivalent of equation (8)

$$W_t(b_t, e_t) = \max\{K, \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t\alpha + \delta q_{t+1}\alpha + \delta W_{t+1}(\alpha, b_{t+1}, e_{t+1})\}\}. \tag{23}$$

The fisherman exits if $K > \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t\alpha + \delta q_{t+1}\alpha + \delta W_{t+1}(\alpha, b_{t+1}, e_{t+1})\}$. This exit decision is independent of the holdings α^i_{t-1}. As before, the decisions as to quota and technology are also independent of the holdings of quota from the previous period.

Suppose that the fisherman can decide each period whether to exit or enter. Then we need to consider two situations - when she is in and when she is out. When she is in the value calculation looks just like the above except for the continuation value. It is

$$v_t(in, \alpha_{t-1}, b_t, e_t) = \max\{K_t + q_t\alpha_{t-1} + \delta v_{t+q}(out, \alpha_t, b_{t+1}, e_{t+q}), \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t(\alpha - \alpha_{t-1}) + \delta v_{t+1}(in, \alpha, b_{t+1}, e_{t+1})\}\}. \tag{24}$$

When she is out it is

$$v_t(out, \alpha_{t-1}, b_t, e_t) = \max\{q_t\alpha_{t-1} + \delta v_{t+q}(out, \alpha_t, b_{t+1}, e_{t+q}), \max_{\alpha,\tau}\{p\alpha A(b_t, e_t) - c(\alpha A(b_t, e_t), \tau, b_t, e_t) - q_t(\alpha - \alpha_{t-1}) + \delta v_{t+1}(in, \alpha, b_{t+1}, e_{t+1})\} - K_t\}. \tag{25}$$

It is true that $v_t(out, \alpha_{t-1}, b_t, e_t) = v_t(in, \alpha_{t-1}, b_t, e_t) - K_t$. It is also true, as before, that the entry and exit decisions as well as the fishing and technology decisions at time t are all independent of the quota holdings, α^i_{t-1} at time $t-1$.

The entry and exit decisions do not change any of the differential results in the main body of this paper.

Appendix III Uniform Price Clock Auction

The uniform price, clock auction is one of the easiest auctions to run and to participate in. It is an iterative auction that proceeds in rounds. I will describe how it would work for an IFQ quota marketplace.[29]

In the beginning the auctioneer lets everyone know the quantity of quota available and an opening price. Then all bidders are given a period of time to submit a bid.[30] Their bid is simply a quantity: how much they would like to buy at this price.[31] Bidders do this without seeing each other's bids. At the end of the bidding period the auctioneer adds up the bids. If the aggregate bid is larger than the quantity available, the price is raised by one increment.[32] This is the origin of the name "clock auction". The price ticks up one increment per bidding period, in clock-work precision, until the auction ends. The new price is posted and a new bidding period is opened.[33] Bidders are asked to submit new bids.[34] After re-submission, the auctioneer again adds up the quantities. If the aggregate quantity is larger than the amount available, the auction continues. If not, the auction stops.

At this point there is a final design choice. One could just accept the result of the auction. That is, one could give each buyer who bid in the last round the quantity they bid at the price for that round. However, it

[29]The auction I describe here is a particularly simple version of that proposed by [7]. Ours is simpler since we are only auctioning off a single homogeneous commodity, the quota.

[30]The bid submission time period is a design choice. It is usually somewhere between 10 minutes and an hour. Short periods move the auction along at a fast rate. Slow periods give bidders more time to contemplate and compute their bidding strategy.

[31]It is possible to allow sellers, other than the auctioneer, enter bids also. That would simply be a negative quantity: how much they were willing to sell at the current price. This is often referred to as a two-sided auction and is similar to a call market.

[32]The size of the increment is a design choice. High increments move the auction along at a fast rate. Slow increments allow more gains to be captured.

[33]There is a design choice that can be made here as to whether the bidders should be informed about what each of them bid. The answer is no for the individual bids if one is worried about collusion. The answer is no for the aggregate if one wants to encourage active participation by all in every round.

[34]There is still another design choice at this point. Should bidders be allowed to withdraw their previous bid? If they did so they could then either forego bidding or bid something totally different. Some argue that buyers should only be able to lower their quantity demanded. This is called an activity rule. Some say it does not matter. Activity rules move the auction along at a fast rate. But activity rules limit the options of bidders and can cause inefficient outcomes.

is possible that this does not fully exhaust the amount of quotas that are available. The drop in the aggregate bids can be more than the excess in the previous round. If these auctions are held often enough, this is not a problem. The excess supply can simply be inventoried and made available at the next auction. But if the auctions are infrequent and inventorying quota can cause difficulties in the IFQ process, then the auction needs to continue into another "phase." In this second phase, past bids are "re-submitted" into the auction along with the bids from the last round and the collection that maximizes the gains from trade are provisionally accepted.[35] If that collection displaces one of the bidders in the last period then the price is increased by one increment and the auction continues as in the first phase. If no one is displaced in the second phase, the auction stops.

The first phase is really easy for both auctioneer and bidder. The auctioneer has a very simple calculation. Does the quantity bid exceed the amount supplied? The incumbents have a simple calculation. They only need decide at any price whether (a) they want more quota because they expect their costs to be lower than that price or (b) they want to sell quota because they expect their costs to be higher than that price. Potential entrants are on a level playing field since they can see the price and decide whether they are willing to pay that much in order to enter the fishery.

The second phase may seem complicated but bidders need not even know that it happened. Bidders need only know that the price has increased and bidding has resumed. Also, there is ample evidence from both laboratory trials with this auction as well as commercial applications, that it is relatively easy to learn how to bid.

With straight-forward bidding, the auction will exhaust all gains from trade. That is, the buyers with the highest value for the items will win them. The sellers with the lowest value for the items will sell them. The final price will be the equilibrium price. This is a completely transparent process which encourages liquidity.

[35] This is a simple optimization program which I will not present here.