A CERTIFICATE-LEASING PROGRAM FOR MARINE RESOURCE DEVELOPMENT

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ABSTRACT

In response to recent extended-jurisdiction legislation, we propose a new two-part program for fishery management. First, access to the fishery is controlled by issuing certificates. Certificate holders are entitled to catch a certain fraction of the quota, set each season by management. Quota rights may be traded among fishermen to allow exit and entry via a market mechanism. The certificate system has the desirable properties of minimizing costs of fishing, and creating fair division of fishery rents. Second, some of the uncertain variations in fishermen's income are eliminated by a government partial insurance plan. Under the plan, a share of the fishermen's income is paid to the government in "good fishing years", in return for government assistance to fishermen in "bad years". Thus, some of the risk borne by fishermen is transferred to the government, which possesses superior risk bearing capabilities. The use of this program in the northern anchovy fishery is analyzed for its impact on industry efficiency and income distribution.

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1. INTRODUCTION

The Fisheries Conservation and Management Act of 1976 (PL 94-265) now enables the United States to effectively govern its fisheries. For the first time it will have jurisdiction within 200 miles of its shores. Policy changes are needed to correct two primary problems that have historically plagued management programs. First, the common property status of fisheries has led to over-exploitation and excess capacity in fishing industries. Second, variations in the stock abundance and fluctuations in consumer demand make fishing a risky occupation. Yet no provisions have been made for the government or private sector to share some of these risks which fishermen bear. A two-part program for alleviating these problems is evaluated in this report.

In the first part, we suggest a property rights approach to controlling access to the fishery. It relies on the issuance of stock certificates and on a market in fish tickets to create virtual property rights in the fishery. Certificate holders may catch a certain fraction of the seasonal quota set by management. Certificates are transferable to allow exit from and entry into the fishery. Each season certificate holders are allocated a certain number of fish tickets; each ticket entitles the holder to catch a certain fraction of the quota. Tickets can be bought and sold on a market and the market price of the ticket reflects the scarcity value of the fish. Rents from the fishery are collected by certificate holders. By controlling the supply and distribution of certificates and fish tickets, the manager can limit the catch, minimize the costs of fishing, and insure a fair split of the fishery rents among different user groups.

In the second part, we propose a leasing program whereby the government accepts some of the risks fishermen now bear. Under the lease, the manager hires boats to fish and fishermen's wages are contingent on the value of their catch. Normally, fluctuations in stock abundance and consumer demand cause fishing income to vary considerably. The lease agreement will allow the government to compensate fishermen in "bad years", in return for a share of their income in "good years." The manager's ability to monitor the fishermen's actions will determine the form of remuneration. This in turn will determine the efficiency and risk sharing properties of the lease.

We believe that in combination, these proposed programs offer attractive alternatives to current management practices. This report provides a theoretical analysis of access control and leasing as management tools, and assesses the prospects for employing these tools in the northern anchovy fishery. In Section 2 of the material to follow, we discuss the theory of controlling entry and fishing inputs. The reasons for controlling access to a fishery and the deficiencies of limited entry programs are evaluated. A certificate program for access control is proposed and analyzed in terms of the costs of the plan, the plan's congruence with noneconomic goals of management, and the problems involved in allocating fishery rents.

In Section 3 government leases to insure fishermen against large variations in income are examined. A theory of optimal leasing is derived. We find that risk sharing arrangements provide fishermen with a cushion against large income fluctuations. However, guaranteed incomes may cause fishermen to shirk. An incentive problem or moral hazard may thus arise if the manager cannot directly observe the amount of effort fishermen supply. To avoid this difficulty, bonus and penalty payments for rewarding (penalizing) the fishermen whenever catches are abnormally large (small) can be used.

Section 4 discusses the practicality of using access control and leasing in the northern anchovy fishery. Uncertainty about jurisdiction, conflict between commercial and recreation fishermen, and large fluctuations in fishery income are identified as important anchovy management problems. Our proposed programs are evaluated for their ability to solve these problems and to satisfy goals established by the Pacific Fishery Management Council. Attention is given to the administrative costs and to the distributive effects of these plans.

Section 5 concludes with a summary of results and suggestions for future research.

2. CONTROLLING ACCESS TO A FISHERY

That common property fisheries are often over-fished is well known. Yet, the various reasons for this are apparently not well understood. Most of the proposed management programs to prevent common property inefficiencies try to limit entry into the fishery. This approach is oblique and does not in fact reduce incentives to over-fish. As a result, long run adjustments to these management plans by the fishing industry cause further inefficiencies.

To substantiate these claims, we review the reasons for controlling access to a fishery in Section 2.1. This enables use to then point out the deficiencies of limited entry programs in Section 2.2. A different type of access control program is proposed in Section 2.3. It relies on the issuance of stock certificates and on a market in fish tickets to create virtual property rights in the fishery.[1] This, we believe, directly addresses the central problem of a common property resource. The following three sections examine, respectively, the cost aspects of the plan, the plan's congruence with noneconomic goals of fishery management, and the problems involved in allocating fishery rents.

2.1. The Theory of Access Control

A common property fishery is over-fished for one fundamental reason: use of the resource is regarded as being free. A plan to control access to the fishery can either aim directly at this central reason or, less effectively, at some of its consequences. We must discuss here the theory behind access control in order to determine the actual targets of a management plan.

2.1.a Valuation of Fish Stocks

The output of a fishing enterprise is simply fish on the dock. Several inputs are necessary to produce this output: boats, gear, labor and most importantly, fish in the sea. These factors may have use in alternative activities. If the value of a factor in one of these other activities increases then, all else being equal, that activity should use more of the factor. With scarce factors this can be accomplished only if fishermen use less of the factor for current fishing. Assuming perfect factor markets, a firm will use less of the factor because its price increases as its value in another activity increases. But in a free access fishery, fishermen do not have to pay a price for fish in the sea. Consequently, the use of the resource for current fishing does not reflect its value in other activities. This is the basic reason for over-fishing.

The fish in the sea used by a single fisherman in a day of fishing can have value in several other activities. First, they have value to other fishermen on following days since a decreasing fish stock causes unit fishing costs to rise. The fisherman imposes this stock externality when, for example, the time it takes to find fish or the number of fish caught per set of the net depend on the abundance of fish.

Second, preditor-prey relationships can cause one species to be valued for its effects on the abundance of other commercial species. This value is created by what is called the interspecies externality.

A more apparent alternative use for fish in the sea is simply future consumption. Each fish in the sea not used for current fishing contributes to future fishing, directly by being harvestable itself, and indirectly by increasing the harvestable biomass through the growth of itself and its progeny. When net growth in the population is desired, as when the fishery is depleted, additional value accrues to the fish for their growth potential. A fisherman who reduces the fish stock available for future fishing without bearing the cost which such a reduction entails for future fishermen can be said to impose an intertemporal externality.

The sum of these values of fish in activities other than current fishing is rent; a fish should be used for current fishing only if its value for current fishing is greater than this sum. But fishermen in a free access fishery do not pay this rent for fish in the sea. Acting as though fish were a free good, they utilize the fish stock to the point where its marginal value for current fishing decreases to zero rather than to the marginal value of its use in alternative activities.

2.1.b. Free Entry

Exploitation of a free access fishery is excessive even if entry is restricted. None of the above argument is couched in the usual terms of free entry, causing the rent earned by the resource to be "dissipated" and profits driven to zero. Suppose the number of fishing firms is restricted to be small but still greater than one. Possibly each fisherman's share of the catch will be large enough for him to perceive the future costs he bears by current harvesting. But we will not take account of the costs he imposes upon the other fishermen. Consequently, use of the resource will still be excessive.[2]

Free entry does exacerbate the over-fishing problem, however. Entry will occur in a free access fishery until a firm's revenue is equal to the costs it incurs. Since the fishing firm does not bear the cost associated with its withdrawal of fish from other activities, net social benefits are negative at a free entry equilibrium. Entry is excessive.

The zero profit associated with free entry equilibria is often cited as an imperfection of a common property fishery. Actually, if each fishing firm bore the cost of its use of fish in the sea, then entry until profits become zero ("normal") is socially optimal. This is how entry drives average costs to their minima in perfect markets.

Another situation in which free entry leads directly to inefficiency occurs when the presence of one fishing boat makes fishing more costly for other boats. This crowding externality causes the use of boats and gear to appear less costly than they really are to an individual fisherman. The result is excessive use of boat and gear inputs, just as the various externalities that give unacknowledged value to fish in the sea result in excessive use of that input.

We have shown that excessive use of fish stocks is a result of each fisherman not bearing the cost of withdrawing fish from the concurrent or future activities of other fishermen. Excessive entry is a consequence rather than a cause of the incentive to over-fish, except when crowding externalities are present.

The determination of optimal stock levels, harvesting rates and, in the presence of crowding externalities, numbers of boats and gear are difficult bioeconomic problems beyond the scope of this study. Subsequently we shall assume they have been determined in some fashion. The focus in this Section is on management plans designed for their implementation.

2.2 Limited Entry and Input Program

Restriction of entry and inputs is the primary instrument of most proposals to control access to a fishery. For example, a fixed number of licenses, vested either in individuals or in vessels, may be allocated in some fashion to limit the amount of "effort" applied to fishing.

As the previous discussion reveals, excessive entry is only a consequence of the fundamental problem: the free use of valuable fish in the sea. Excessive "effort", if measured by the amount of capital or labor inputs used in fishing, results only because these inputs are complementary to the fish stock input. Imposing a ceiling on the number of vessel or fishermen inputs does not eliminate the incentive to over-utilize the fish stock. Consequently, fishermen will adjust to entry restrictions in predictable ways that still lead to excessive use of the resource.

2.2.a. Input Substitutions

The result of restricting one input is the substitution of it with other inputs. Because the incentive to over-fish the resource still exists, the substitutes chosen will be complementary to the fish stock. That is, substitutes will be chosen that allow the fishing firm to increase its use of fish in the sea. Likely inputs to substitute for restricted boats or fishermen are

(i) capital, in the form of larger boats and more gear;

(ii) time, by fishing longer hours made possible by, e.g., cutting transportation times with faster boats and locating processor ships in the fishery;

(iii) technology, in the form of more sophisticated gear and fish-finding devices; and

(iv) other fisheries, which are substituted when a boat that is unable to obtain a license for a restricted fishery fishes an unrestricted one instead.

The substitutions induced by binding constraints on entry may make the problems worse. A restriction on input choice caused by limiting entry will not allow costs to be minimized. Hence the long-run adjustments to entry restrictions may create demands on the resource that are as great as under free entry. But in addition, the total costs of catching that amount of fish will be greater.

The limited entry plans currently in effect have clearly induced substitutions of the above types. For example, we refer to Fraser's [1977] study of the limited entry program started in 1969 for the British

Columbia salmon fleet. The plan vested licenses in vessels, but had initially an unrestricted vessel replacement provision. By 1970, 76 boats with a total capacity of 186 tons had been replaced by boats with a total capacity of 596 tons. The replacement rule was then amended with a ton-by-ton provision. Despite this, the capital value of the fleet by 1975 was almost 20% greater than the value it would have achieved under free entry. Much of the increase was due to the increase from 400 to 500 in number of vessels that use purse-seine nets, the most capital intensive type of gear for salmon fishing. Because of these industry adjustments, costs increased without any significant change in landings, despite a reduction in boat numbers. One can observe similar adjustments in other fisheries where limited entry plans have been in effect, e.g., in the Australian rock lobster fishery (see Meany (1978)) and in the Maine and Massachusetts lobster fisheries (see Smith and Peterson (1977)).

2.2.b <u>Restricting Substitutes</u>

Substitutions caused by input limitations can be halted by also restricting the use of substitutes. For example, in British Columbia the ton-by-ton weight rule and also a foot-for-foot length rule were amended to the replacement rule in attempts to limit the substitution of capital. Alaska's new limited entry program controls amounts and types of gear as well as vessels and fishermen. Season and quota restrictions are common instruments to limit the use of time.

Limiting substitute inputs has two undesirable consequences. First, the administrative and enforcement costs of regulation can become enormous. The allocation of different kinds of permits according to various criteria is time consuming and costly. Legal costs incurred in the process of allocating permits are high. Costs of obtaining information on the use of inputs are great. On-board inspections to enforce gear regulations are more costly than on-shore procedures. The incentive to violate controls increases as more controls are adopted, so that enforcement costs are driven higher. As the use of more inputs is restricted, other inputs will be found to substitute for the restricted ones. Hence the imposition of more controls becomes necessary, further increasing management costs and abridging fishermen's freedom of choice.

Second, controlled input use restricts fishermen's attempts to reduce their costs. This occurs because of the imposed inability to adjust the amounts of controlled inputs. Perhaps more important are the long-run effects on technological innovation. Incentives for fishermen to adopt cost-saving innovations are eliminated when regulations lock them into a current technology using the controlled inputs. Technological advance has recently been rapid in many fisheries, so that freezing it would quickly result in unnecessary costs imposed by out-of-date technology.

2.2.c. Multispecies Fisheries

One other flaw of limited entry programs occurs in multi-species fisheries. When a fisherman has the gear and permits to catch several types of fish, a species-specific permit does not serve as even a proxy for a measure of use of that species. Since permit holders allocate effort among several species, as a species becomes more valuable, more time will be spent fishing for it. If many fishermen hold permits to fish several species, then the flow of effort from one species to another as a result of market forces will be absolutely no incentive to reduce demands on one species relative to another species that can be caught by the same fishermen.

We have shown that limited entry programs restrict the wrong inputs, boats or fishermen, rather than the one which is overutilized, fish in the sea. When boats or fishermen are restricted, substitution of capital, time, technology, and other species occurs. These substitutes allow greater demands to be put on fish stocks. Restricting the substitution possibilities increases management costs and further reduces the ability of fishermen to minimize costs. Finally, we indicated that sudden increases in the utilization of one species are completely unimpeded by limited entry programs when fishermen hold permits for several species.

2.3 Stock Certificates and Fish Tickets

In this section we outline an alternative management program. Its structure is very similar to that of the plan proposed by Francis Christy [1977]. Only the bare bones of the plan are presented here, reserving discussion of details for later.

The approach is designed to directly attack the problem by making fishermen pay the costs of withdrawing fish from the sea. A tax on catch could theoretically be imposed for this purpose, but it has two fatal drawbacks: (1) a tax is politically unpopular and hence unfeasible, and (2) the imposition of a tax on a depleted fishery cannot be afforded in the short-run by fishermen whose profits have been driven to subsistence levels.

Instead of taxes, we propose that management establish a seasonal quota for the fishery. Ideally, the quota is established at the level at which fishermen would fish if they had to pay the correct "user" costs for fish in the sea.

Ownership rights to shares of the quota are allocated to private agents in the form of stock certificates. Each stock certificate confers to its owner the rights to a fraction of each seasonal quota. They are transferable to allow exit and entry via a market mechanism. Fisherman acquire fishing rights by purchasing fish tickets. Each fish ticket allows the fisherman to catch a fixed amount of fish. The fishery manager at the beginning of a season issues to each certificate owner the number of tickets to which the owner is entitled that season. Then the fisherman must either purchase tickets from a certificate holder or, if he owns certificates himself, simply use the tickets he has received. Presumably, fishermen will be willing to pay the difference between the market value of the fish and the costs of catching them for a certificate. The price of the certificate will thus reflect the scarcity or rent value of the fish in alternate current fishing activities. The ways in which certificates can be initially allocated will be discussed later. The method of allocation is important because the rents fishermen will pay for fish in the sea will be received by certificate holders.

In addition to a quota on catch, there may be need to restrict the number of boats in some fisheries because of crowding externalities. This can be done by issuing a limited number of fishing licenses, much as its proposed in limited entry plans. But we emphasize that the role of licenses in this program is secondary to that of stock certificates in alleviating the common property problems of a fishery.

The issuance of licenses may be desirable even when crowding externalities are not present. If the returns to fishing are uncertain, then a risk sharing contract can be incorporated into a license, allowing the government to assume part of the risk of fishing. For this purpose, the number of licenses should not be restricted. Possible risk sharing contracts will be discussed at length in Section 3.

The stock certificates, fish tickets, and fishing licenses form the core of the proposed program. None of the standard, cost-increasing regulations, such as short seasons and gear restrictions, should be necessary. In the next three sections we discuss the costs of the program, its desirability in terms of other management goals, and the ways in which certificates and licenses can be allocated.

2.4 Cost Analysis

Three kinds of costs are associated with a management plan: (1) the costs of fishing which arises from the plan, (2) the risk costs determined by the way uncertainty is treated by the plan, and (3) the costs of administering the plan. We analyze each cost in turn.

2.4.a Fishing Costs

Effects of the program on fishing costs are minimal. No inefficient techniques need be used, and no efficient techniques are barred from being used. Each fisherman has the flexibility and the incentive to minimize costs. The costs he minimizes are the true costs of fishing, since factor prices reflect the scarcity value of the fish in the sea. Because cost minimizing incentives are maintained and unrestrained, demand for technological improvements in fishing should stimulate innovation for cost reduction.

The ticket market will function to lower total fishing costs. This occurs simply because efficient fishermen will be able to pay a higher price for fish tickets. Hence more efficient fishermen will displace inefficient fishermen, resulting in lower total fishing costs.

2.4.b Risk Costs

One kind of risk a fishermen currently bears can be reduced by the market in fish tickets. The uncertainty of "bad" or "good" luck is specific to each fisherman. It is not related to fluctuations in weather or stock, which affect all fishermen. This type of uncertainty will not affect the total amount of fish caught, as the uncorrelated streaks of "bad" and "good luck" will cancel. The ticket market alleviates this risk. Fishermen having a good season can obtain more tickets than their own certificates entitle them to, whereas fishermen having a bad season can reduce their losses by selling tickets they have either previously purchased or have obtained by holding certificates. Considerable smoothing of variations in fishermen's incomes should be achieved.

The other primary source of uncertainty in fishing occurs in demand, weather, and fish stocks. These random factors are experienced in the same way by all fishermen. Hence nothing is gained by fishermen sharing these risks among themselves through the ticket market.

Futures contracts in tickets for seasons could allow intertemporal sharing among fishermen of seasonal risks. A futures market may also serve to correct quotas that are incorrectly set, since market actions should have two effects: (1) carry tickets over to subsequent seasons when the season's quota is set too high; and (2) bring tickets forward from the future if the quota is set too low. But the management problem of determining and enforcing quotas when these futures contracts, particularly those used to bring tickets forward are allowed, are terribly complex. Consequently we do not recommend a futures market in tickets, although further study may prove it desirable. Instead we suggest that interseasonal risks incurred by fishermen be shared with the government. As mentioned before, this can be done by attaching a risk sharing contract to the license a fisherman acquires in order to fish.

2.4.c Management Costs

Enforcement costs for the certificate plan should be low. Only inspection at the dock or processing plant is required to insure that fishermen possess the tickets required for their catch. Since the on-dock inspection or a used ticket retrieval system can provide accurate data on catch rates, the ticket program provides much of the data necessary to set quotas at no extra costs. In fact, such data is already collected in some fisheries so that the set-up costs of the ticket program should be minimal in these instances. Other administrative costs will be considered in the next two sections, but certainly the basic costs considered here are relatively low.

2.5 Management Aims and Options

This section suggests some management and noneconomic goals that an access control program should achieve. Specific ways of administering the certificate-ticket plan can be devised to meet most of these goals. Questions of allocation are postponed until the next Section.

2.5.a Multispecies Fisheries

The problems of a multispecies fishery are well addressed by the certificate-ticket plan. It was mentioned in Section 2 that a limited entry program cannot by itself reduce demands on one species relative to another when vessels have permits for several species. Yet, when only minor gear changes allow several types of fish to be caught in the same area, restricting a boat from fishing for more than one type is economically inefficient. The certificate-ticket plan allows fishermen to catch several species while still creating incentives to fish for one species rather than for another. If one species is considered to be overfished relative to another, quotas can be set so that the price of a ticket for the first species will be greater than the price of a ticket for the second species. Fishermen will then naturally shift their efforts towards the second species.

The ticket market imparts additional flexibility to a fisherman in a multispecies fishery. A fisherman cannot predict beforehand what he will catch. For example, a boat beginning a day of fishing will be most efficient if its hold is filled with the first kind of fish encountered, provided the alternative is to continue searching for another kind of fish that is not much more profitable. On a day-to-day basis the ticket market can permit flexibility by letting fishermen purchase the required tickets after bringing in the day's catch. Of course, on a seasonal average the catch of each type of fish must not exceed its quota.

2.5.b Exceeding the Quota

What can be done if the quota is exceeded? Fishermen sell fish at the end of each fishing trip. Since they cannot sell fish without obtaining tickets, the quota can only be exceeded on the last fishing trips of the season. It cannot be greatly exceeded if the total amount caught in one trip of the fleet is small relative to the season quota, as it would be in many fisheries. If the quota is exceeded, then some fishermen returning from their final trip of the season will not be able to purchase enough tickets for their catch. But to avoid waste, they should be allowed to sell their catch. They should pay the market price of tickets for their use of fish in the sea, and perhaps also a penalty fee assessed to reduce incentives to make excessively long "last" fishing trips.

2.5.c Quota Adjustment

Because of the incomplete information on stock abundance, the manager may incorrectly set the quota at the beginning of a season. The ticket market can serve both to signal that a quota has been incorrectly set and to allow intraseasonal adjustments to the quota. Ticket prices reflect the marginal values of fish in the sea at the announced quota. Hence extremes either way in ticket prices signal that the quota has been set too high or too low.

The government can influence the season quota by purchasing tickets to decrease it. Conversely, it can increase the quota by simply issuing more tickets to certificate holders. While the government could also increase the quota by directly selling tickets, we do not suggest this unless the government owns corresponding stock certificates. Otherwise the meaning and hence the value of a stock certificate is unclear. This is not fair to certificate holders and it destabilizes the certificate market. Careful consideration must be given to the reasons for quota adjustment, for the quota-setting body may be pressured to make adjustments merely to subsidize certificate holders or fishermen.

The government might wish to enter the ticket market if fishermen at the beginning of a season impose a declining yield externality upon fishermen at the end of the season by significantly reducing the stock level. If tickets are issued only at the beginning of the season, the equilibrium conditions force the (discounted present value) price of a ticket to be the same at all times during which private certificate holders sell tickets. If they sell throughout the season, tickets at the beginning of the season cannot have a higher price to reflect the cost imposed upon fishermen at the end of the season. The government can rectify the problem by selling tickets, after the private sellers are sold out, at prices lower than the prices the privately-sold tickets had commanded. The government may obtain the tickets by purchasing them early in the season or by owning certificates. Alternatively, the government may simply issue tickets on a weekly instead of a seasonal basis at a rate reflecting the externality.

2.5.d Recreational Fishing

Recreational fishermen pose another problem for fishery management. Recreational catches of some fish are comparable to commercial catches. However, the large numbers and irregular efforts of recreational fishermen make them politically and administratively costly to regulate. The costs of requiring recreational fishermen to buy tickets would be great, but probably not greater than the costs of enforcing bag limits. The transaction costs borne by recreational fishermen under a ticket plan would, however, be greater than those they bear under bag limit programs.

There is no economic reason for recreation fishing tickets to be priced differently than commercial fishing tickets. But if political realities dictate that the prices should be different, then two types of stock certificates can be allocated, two quotas set, and two types of tickets issued. The determination of the relative sizes of the two quotas will dictate the prices of the tickets.

2.5.e Acceptability

The ticket market preserves freedom of choice and alleviates the odiousness of quotas to the reputed, ruggedly individualistic fisherman. Although the purchase of tickets increases the cost of fishing to a fisherman, he will not suffer the initial, unaffordable burden a tax would impose if he is also issued stock certificates. Initially the quotas need not be set too rigidly, for the flexibility of the system would allow them to be easily tightened at a gradual rate. Transitional hardships can thus be minimized, and an immediate forced exodus from the industry can be avoided. The main points of contention would probably be the behavior of the government in the ticket market and the method of allocating stock certificates and fishing licenses.

2.5.f Summary

Unlike a limited entry program, the certificate-ticket plan provides incentives to fish more for one species than for another in a multispecies fishery. The ticket market and the possibility of keeping tickets after a day of fishing allow fishermen day-to-day flexibility in their choice of fish to catch. Ticket prices provide a guide for penalizing fishermen who exceed the quota, although the fine may have to be set higher than the ticket price to discourage excessively long fishing trips at the end of seasons. Extreme fluctuations in ticket prices will signal that the quota was incorrectly set. The manager can correct the quota by either issuing or purchasing more tickets. Recreational fishermen could purchase the same tickets as commercial fishermen, or purchase tickets that are good only for recreational fishing. Overall, the flexibility of the certificate-ticket plan, and its lack of rigid, cost-increasing regulations, should make it acceptable to fishermen. Of course, how the certificates and licenses are allocated will greatly affect the plan's acceptablity.

2.6 Allocation of Certificates

The certificate-ticket plan calls for certificate holders to receive the rent attributable to fish in the sea. The allocation of certificates will determine who receives the rent: the government, commercial fishermen, recreational fishermen, processors, or consumers. The Fishery Conservation and Management Act (FCMA) of 1976 apparently requires that the rent be received by fishermen, since it forbids charging fishermen high access fees. But this interpretation is debatable. It is also contrary to the government's "fair price" policy of leasing other natural resources owned by the public. A major advantage of the certificate-ticket plan is the ease with which the allocation of rents can be changed.

2.6.a The Initial Allocation

Initially, both the FCMA and the low incomes of fishermen dictate that the rents be received by fishermen. This can be achieved by issuing stock certificates to fishermen on the basis of historical catch rates and degrees of dependency on the fishery.

To allow for exit and entry, certificates should be transferable. Rules limiting concentration of ownership, processor ownership, or even speculator ownership could be enacted if so desired. However, there are not efficiency reasons for these restrictions, as even complete monopoly ownership of the certificates leads to the same ticket prices and catches, as occurs with a more dispersed ownership. In fact, the transaction costs of the ticket market would be avoided if one large fishing firm owned all certificates and did all the fishing. Only if the solitary firm using the fishery was a monopolist in the market for fish products would monopolistic inefficiencies occur in the fishery.

Monopoly ownership of certificates is not even necessarily inequitable, since it could only be achieved by a buyer purchasing certificates from the fishermen who originally received them. If the price of a certificate is equal to the full discounted present value of the income stream it generates, then the seller merely receives his share of the rents as a lump sum. If the buyer has undue market power, however, as some processors may have, then the seller will not be paid the full value of his certificates. In this case the initial distribution of certificates does not determine the distribution of fishery rents, as the buyer receives claims to rents without fully compensating the sellers for them. Concentration restrictions should then be imposed if certificates are intially allocated to achieve a desired distribution of rents.

With time, the government may wish to resume ownership of certificates in order to add fisheries to the stock of publicly owned resources. The government can achieve this in two ways. The first is simply to issue only fixed-term certificates; after a certain number of years such certificates revert back to the government. The second way is via a certificate buyback program. A buyback program must be used if originally, certificates were issued that forever entitled their owners to fish tickets, i.e., if it was decided that fishermen should receive the entire discounted rent to be earned by the resource.

2.6.b Pricing Certificates

After some certificates have been acquired by the government, various methods for both buying and selling certificates can be used. The easiest way is simply to offer to sell or buy certificates at whatever price they command in the private certificate market. However, the correct price can be found in this marketplace only when the certificate market is competitive and active.

If the market is not competitive and active, then the value of a certificate can be estimated from the discounted present value of the time stream of fish tickets entitled to the owner via the certificate. This calculation requires knowledge of the numbers and values of the tickets that a certificate produces in future seasons, even when ticket markets are active and competitive. Because future quotas are partly determined on the basis of fish population characteristics, they are difficult to predict if these characteristics randomly fluctuate. At best, only probabilistic information about the random income stream a certificate generates may be available; this may not be enough to estimate certificate values. Incomplete insurance markets and differing degrees of risk aversion among certificate holders may preclude agreement on how to calculate expected discounted present values.

2.6.c Auctions

When certificate values cannot be estimated from market data, the government can determine certificate prices by holding auctions. Two criteria must be weighed to decide which type of auction to use. The first relates to sales prices determined by the auction. If they are relatively high, sellers capture most of the rents, and if they are relatively low, buyers will capture most of the rents. If the government wishes to capture as much of the rents as possible, it should choose the type of auction that maximizes its expected revenue net of the auction costs.

It is important to recognize that strategic behavior on the part of bidders can cause the government to receive less rent. As an example, suppose a fixed number of certificates are to be sold in an auction which requires each bidder to submit a schedule specifying the number of certificates he would purchase at various prices. The government may then sell certificates at the price at which the submitted demands equal the fixed supply of certificates. Each buyer receives the number of certificates specified by the schedule he submitted. In this type of auction, which is a natural one to consider for the sale of certificates, a game-theoretic analysis by Wilson [1977] shows that the government may receive no more than half the rent associated with the certificates it sells. This conclusion holds even if the number of bidders is large.

The second criteria for evaluating an auction method concerns the nature of the firms who will be able to buy or sell certificates to the government in the auction. This issue is not one of economic efficiency in fishing, for as argued before, a competitive ticket market does not rely on the identity of certificate holders for efficiency. The issue is rather one of equity. As a hypothetical example, consider an auction in which one certificate is sold to the bidder who submits the highest bonus bid, with the sales price being equal to his bid. If large firms have better access to capital markets and lower risk aversion than small firms, then large firms can submit high bids and will place higher values on the uncertain returns associated with the certificate. The largest firm can then obtain the certificate at a price marginally higher than the maximum price the second largest firm would pay. The result could be further accumulation of wealth in large firms relative to small firms.

The above examples of auctions are not presented as arguments against their use. We merely wish to demonstrate that various types of auctions have perhaps unsuspected properties. Their properties must be studied further and then carefully weighed against each other in order for a choice to be made.

2.6.d Recreational Data

As mentioned previously, a controlled access program for recreational fishing may be politically infeasible. If not, it may still be necessary for recreational fishing for commercial species to be governed by a distinct certificate-ticket plan. Two distributive questions then arise: (1) who should hold recreational certificates, i.e., who should receive the recreational rents, and (2) how should the recreational quota be determined?

The answer to the first question appears straightforward. Because of their numbers and sporadic fishing activities, it is administratively too costly to issue certificates to recreational fishermen in most fisheries. There is also no clear reason for recreational fishermen to receive the rents as well as the product of recreational fishing. The only other alternative is for the government to hold the recreational certificates. Under the proposed plan, recreational fishermen purchase tickets from the government; ticket prices are set by the government so that the recreational quota is not exceeded. The public receives recreational rents.

The question of how to determine the recreational quota is more difficult. It partly involves estimating the relative sizes of the recreational and commercial quotas. To set the recreational quota, the government needs to know the value recreational fishermen place on fishing. Unfortunately, their benefits cannot be estimated from market data, since a recreational catch is not sold. Recreational interests will be inclined to exaggerate recreational benefits from fishing in order to obtain a large quota. However, there is a scheme that may allow the government to obtain accurate valuations from recreational fishermen. We merely mention it here as possibly worthy of future study. It consists of taxing recreational fishermen for their quota points in exactly the right way to insure they will neither under or overestimate their quota demands. These taxes, which could be appended as surcharges on ticket prices, are described in the literature on "demand-revealing processes"; the 1977 spring supplement of Public Choice is devoted to these and related processes.

2.6.e Summary

We have perhaps raised more questions than we have answered in this Section. The allocation of certificates and of quotas determines the size of the rents and who receives them. The question of allocation is hence a sensitive issue. The problem is compounded by non-obvious and not completely understood consequences of some allocation methods.

The two most likely holders of commercial certificates are the government and fishermen. Exchanges of certificates between the two at prices reflecting certificate values can be easily accomplished if the certificate market is active. Otherwise some type of auction may have to be held to determine prices at which the government can buy or sell certificates. A detailed analysis of auctions was not made, but it was pointed out that auctions do not necessarily insure that prices are equal to bidders' true valuations, or that bidders with the same valuations but with different access to capital and risk markets will be treated equally.

The determination of recreational quotas is another thorny problem. This is partly because it involves conflict between recreational and commercial users in the setting of their relative quota sizes, and partly because of the difficulty of determining the value recreational fishermen place on fishing. We indicated that some type of demand-revealing process might be useful in obtaining the true valuations of recreational fishermen.

Although we have not explicitly discussed the allocation of fishing licenses, their allotment is subject to the same considerations as that of certificates. However, their allocation is an issue only if crowding externalities require their numbers to be limited.

2.7 Conclusion

Stock certificates endow individuals with virtual property rights to the fish stock. The ticket market creates a separation between the effort a fisherman exerts and the amount of rent received by a certificate holder. Consequently, the share of the rent created by the fishery that a fisherman receives is determined by the certificates he holds rather than by his own utilization of the resource. This eliminates his incentive to over-fish, and long run adjustments by the fishing industry to circumvent the quotas should not occur. This is one of the primary advantages of the certificate-ticket plan over limited entry programs. Its ease of enforcement, preservation of cost minimization incentives, smoothing of variations in fishermen's income, and the ability to control relative efforts in multispecies fisheries are its other primary benefits.

The most difficult problem with the certificate-ticket proposal is the allocation of certificates. The rent is received by certificate holders, so that certificate distribution is bound to be a controversial issue. Determination of the relative sizes of the recreational and commercial quotas may also cause controversy. We did not have definite answers for these distributive questions, although we looked at some of the issues involved. It must be remembered that any access control plan is designed to create fishery rent and consequently, its distribution will always be a problem.

3. OPTIMAL RISK SHARING CONTRACTS

3.1 Introduction

Fishing is a very risky profession. Variations in the availability of the stock, in the market value of the fish, and in the cost of harvesting them cause large fluctuations in fishermen's income. Consequently, yearly incomes vary depending on the luck of the fishermen and on conditions in the market. In the previous Section we distinguished between two kinds of risks incurred by fishermen: independent risks and common risks. The first kind pertains to the variations in income due to the individual luck of the fishermen in locating the fish and harvesting them. During any season, some boats will be more fortunate than others, and one way to even out the differences in income between boats is through the certificate system as explained above. The second kind of risk is related to variations in prices, in the cost of effort, and in the abundance of the stock, which affects all the fishermen simultaneously. For example, if the yearly stock is an unusually low one, or the price of fish falls, then all fishermen will suffer.

Currently, the only institution providing for the spreading of common risks within the fishery is the share remuneration system whereby crew members and boat owners share in the profits and losses from fishing.[3] There is, however, no provision for the government to share the risks of fishing with the fishermen. This is particularly surprising since the government has better capabilities to disperse risk through pooling and diversification than does the fisherman.

In other resource industries, government risk sharing is common. For example, under the royalty system used for the leasing of federal oil and natural gas deposits, the government shares some of the drilling risks with the developer. A portion of the amount paid by the developer to the government for the rights to drill are contingent on the value of the resource recovered. Thus, if a dry well is drilled, part of the cost to the developer is borne by the government in the form of reduced lease payments.

Historically, the problems of depletion and excessive capitalization arising from the common property status of the fishery have been the primary concern of fishing management. This, we believe, is the reason that the risk bearing costs incurred by fishermen have been overlooked in formulating management policy. The recent Extended Jurisdiction Legislation now enables managers to prevent depletion and control the use of fishery resources. Thus more attention can be given to reducing the common risks that fishermen face. In fact, the reduction of risk is currently an objective of the regional councils charged with prescribing management policy for national fisheries.[4]

One method of providing risk sharing opportunities is through the lease contract. Under the lease the government and the boat owner agree to a payment plan whereby both parties share in the profits and losses from fishing. It is important to realize that the lease, which is primarily a device for the government to share the risks of fishing with the boat owners and crewmen, is intended to be used in conjunction with the certificate-ticket plan. The allocation of certificates and

and the operation of the ticket market by the fishery manager serve to distribute the rents generated by fishing, and to direct the fishery resource into various uses. The fishermen acquire the rights to fish by purchasing fish tickets. The price of these tickets is a part of the boat's fishing costs. At the end of the season the net income earned by the boat is computed and payments between the government and the boat owner are made, depending on the stipulations of the lease agreement.

The form this payment takes determines the efficiency and risk sharing properties of the lease. Currently in most fisheries, the manager receives a small fixed licensing fee (possibly zero) from the fishermen, who then retain whatever net revenues they earn from fishing. The problem with this scheme is that the fishermen end up incurring all the risks. An alternative plan is for the manager to hire the fishermen to harvest the resource at a fixed wage. In this instance, the government would bear all the risk, while the fishermen would receive a guaranteed income. Unfortunately, moral hazard problems would arise here insofar as a lease guaranteeing fishermen a certain income would reduce incentives for them to provide the optimal amount of effort to harvest the resource. Thus, some care is required to design a risk sharing agreement which does not destroy work incentives.

In the analysis to follow, we want to examine how the form of the payment schedule affects the degree of risk sharing and the supply of effort that occur with the lease contract. The kind of information the manager has about the fishermen's actions and about the fishing conditions turns out to be the crucial factor in determining the optimal type of payment. We are interested in knowing: 1) Should the manager pay the fishermen a straight salary; 2) Should the fishermen rent out the lease rights from the manager; or 3) Would some other form of payment be preferred, given the information available to the manager? In what follows the basic model of the fishery is presented in Section 3.2. Conditions for the construction of efficient leases are presented in Section 3.3. There, we conclude that the manager must be able to monitor either the effort supplied by fishermen or other variables affecting the fishermen's catch in order to provide efficient risk sharing opportunities. Section 3.4 deals with leasing in situations where the manager possesses incomplete information about the fishermen's actions and fishing conditions.

3.2 The Model

The efficiency and risk spreading properties of the lease are analyzed using the following simplified model of the fishery. Assume the manager of a single species fishery[5] has constructed a program to maximize the net social benefits from the resouce, taking into account the present and future economic value of the resource, the biological interaction between this fishery and others, the natural fluctuations in the growth of the resource, and any other relevant factors. Once the optimal harvesting strategy and catch quotas are determined, the manager allocates certificates to various individuals according to some criterion of fairness (perhaps according to historical catch).

Each season, certificate holders are entitled to a specified number of fish tickets. The tickets may be used for fishing or they may be traded to other fishermen. In either case it is the certificate holders who capture the rents from the fishery.

The fishermen who harvest the resource may sign a lease agreement with the fishery manager. The lease is designed to provide risk sharing opportunities for the fisherman and to promote efficiency in harvesting. Under normal circumstances the number of boats operating under the lease system is unrestricted. Recall that overcapitalization and over-fishing are controlled by the certificate-ticket plan. However, should crowding externalities occur in the fishery, the leasing program could be used to restrict the number of boats and to regulate fishing activities. In this situation, the lease would also serve as a license for boats to operate in the fishery. The lease specifications would include the rights granted to the boat (fishing duration, gear to be used, area to be fished) as well as the provisions for risk sharing.

Assume that N boats are each covered under a separate lease agreement with the manager. Given the conditions of the lease, each boat chooses a level of effort E to devote to harvesting the resource. Following the conventional fisheries literature, E is an aggregate measure of the various inputs used in the fishing process. The payoff to the fishermen allocating a given amount of effort is equal to the total revenue from the catch, minus the costs of effort, plus the net revenue from the sale of fish tickets. If the boat catches more (less) than its allocation of fish tickets, it will be required to purchase additional (sell the excess) tickets, thus realizing negative (positive) net revenues from these sales. The returns W earned by a boat are random and are given by

$$W = W(E,\theta) \tag{1}$$

The variable θ may be used to measure the stock abundance, the market price of fish, or perhaps the cost of effort. θ is random to reflect the variations in these factors which occur and cause fishermen's income to be uncertain. We assume that each boat owner must decide on a level of E before knowing the value of θ, that is, before knowing what the fishing conditions will be or what the market price of the fish will be. Consequently, the fishermen will choose E based on the information available to them at the time fishing starts. The time frame we are dealing with is presumed to be short, so that adjustments in E which are made after fishing begins are relatively minor. In choosing effort, boat owners know that θ is distributed according to the probability density function

$$f(\theta) > 0, \ \underline{\theta} < \theta \leq \overline{\theta} \tag{2}$$

Managers are assumed to have the same information about θ as the fishermen.

Notice that in our model W, the return to an individual boat, does not explicitly depend on the effort level supplied by the other boats in the fishery. We are assuming that there are a sufficiently large number of boats operating in the fishery so that each fisherman takes his return function W as given, and does not perceive that his actions will have any impact on the effort supplied by other boats. We also assume that the fishermen are rational in their expectations, insofar as their perceived payoff W turns out to be the actual payoff they receive, given E and state of the world θ. When N is small, the analysis becomes more complicated for then it must be regarded as an N-person noncooperative game between the fishermen (See Lewis 1978).

The sharing of the fishermen's profits and losses with the manager is accomplished with a transfer payment schedule P. P is a net payment made by the fishermen to the manager. Net payments may be negative, corresponding to a government subsidy paid to the fishermen when their income is low, or P may be positive to represent a profits share paid to the manager when the fishermen's income is high. The transfer payments allow the fishermen to hedge against the possibility of a low income year by securing government subsidies in return for paying the government a share of the profits in high income years.

The form of the payment schedule determines the risk sharing and efficiency properties of the lease. Payments might be contingent on E, on the state of the world θ, or on W, depending upon which of these variables can be observed by both the fishermen and the manager. We shall see that the manager's ability to observe and monitor these variables determines the form of the payment schedule and the incentives for the fishermen to supply effort. For example, the manager may want to make payments contingent on E, as a means of inducing the fishermen to supply an efficient amount of effort. However, it seems likely that the manager will not be able to observe E directly, though he may have some idea of its value by observing the catch, or the number of days a boat spends fishing. In this case the manager wants to construct a payments schedule, depending on observable variables like the catch, enabling the government to share the risks of fishing with the boat operators without destroying their work incentives.

In many instances, the manager can observe only a portion of the actual fishing profits because certain costs and revenues accruing to the boat are hidden. We assume that W can be written in terms of two functions, $D(E,\theta)$ which can always be observed at zero cost by the manager, and $C(E,\theta)$ which can not be observed, with

$$W(E,\theta) = D(E,\theta) + C(E,\theta) \tag{3}$$

For example, the manager may be able to calculate the revenues from fishing by monitoring the catch from each boat, but the total effort and the costs of supplying it may be known only by the fishermen. For this case, in terms of equation (3), D the observable portion of W would represent the total revenues from fishing and C which can not be observed would be the cost of effort.

In its most general form, payments are made contingent on D, and possibly E and θ if they can be observed by the manager. Given the payment schedule, P, and an effort allocation E, the boat's net income from the lease, expressed as a function of θ is

$$Z(\theta) = W(E,\theta) - P(D,E,\theta) \tag{4}$$

From the point of view of the fisherman, the lease can be likened to a lottery ticket which pays an amount $Z(\theta)$ depending on which state of the world θ occurs. Different leases provide for different payoff opportunities and the fisherman must have some criteria for judging which of the leases (or lottery tickets) he prefers the most. We shall assume that the value of a lease to the boat owner is calculated by taking the expected value of the utility of income derived from the lease. For a given payment schedule and effort allocation the expected utility of the lease denoted by U^f is

$$U^f = E_\theta u^f(z(\theta)) \tag{5}$$

where u^f ( ) measures the utility of income for the fishermen, and E_θ is the expectations operator taken over all values of θ. We assume that the marginal utility of income is positive ($u^{f'} > 0$), but non increasing in Z ($u^{f''} \leq 0$).[6] The last assumption implies that fishermen are risk neutral and or risk averse with regards to variations in income.[7]

We assume that the fishermen act in their best self interest by choosing an effort level, E(P), to maximize expected utility in (5) given the contract payment schedule P. Let $\hat{Z}(\theta)$ be the fishermen's income from an effort allocation of E(P) and let $\bar{U}^f$ be the value of the boat employed in its best alternative use outside the fishery. Then we require that

$$E_\theta u^f(Z(\theta)) \geq \bar{U}^f \tag{6}$$

otherwise the boat would choose to work elsewhere.

In representing the public interest we assume that the manager is charged with establishing a schedule P to maximize the expected payment from each boat given by

$$V = E_{\theta}\ P(D,E,\theta) \tag{7}$$

subject to the fishermen's "break even" constraint in (6). Recall that most of the rent from fishing goes to the holders of the fish certificates. However, on average, between making transfer payments and collecting profit shares from the fishermen, the government can expect to earn a slight positive return. This return, V, will be used to administer and enforce the leasing program as well as to conduct research on the current and future status of the stock. To maximize V the manager offers schedules which provide the best opportunities for risk sharing consistent with the efficient utilization of the resource. The better the payment schedules are from the point of view of the fishermen, the more they will be willing to a pay under the lease agreement.

3.3 Optimal Leases

For the sake of argument suppose that the manager can select the level of effort for the boats to supply. Then the optimal lease is determined by choosing a payment schedule $P^*(\theta)$ and effort E^* that maximize V and satisfy the break-even constraint in (6). The conditions under which the manager can induce the boat to supply E^* are discussed below. Under the optimal lease the following conditions must be satisfied, (see APPENDIX A for mathematical details).

(a) $Z^*(\theta) = \text{constant, for all } \theta$

(b) $E_\theta W_E(E^*,\theta) = 0$

(Z* is the income that accrues to fishermen when they choose E*.)

According to condition a, payments between the fishermen and the government are arranged so the fishermen receive a fixed income (wage) which is independent of θ or the size of their catch. The government, because of its superior ability to diversify and spread risks, incurs all the risk bearing costs. In condition b, E* is chosen to maximize the expected payoff from fishing.

Of course, it is the fishermen and not the manager who choose effort. For a given payment schedule, boats supply the effort level E(P) that maximizes U^f. Only under the special conditions listed below will the manager be able to offer a payments schedule that induces the fishermen to supply E*.

Result 1 Assume an optimal lease exists and is characterized by conditions (a) and (b). suppose that the manager can observe the portion D(E,θ) of the payoff, accruing to the boat. If, in addition,

(i) the manager can observe the state of nature θ, once it has occurred, or

(ii) the manager can observe E,

then the firm can be induced to supply E* and an optimal lease can be constructed.

The proof of this result is as follows: By the construction of an optimal lease, E* maximizes U^f for the payment schedule $P^*(\theta)$. (See condition (b).) Thus if the manager can offer the boats, the schedule $P^*(\theta)$ they will automatically choose $E^*(\theta)$ since that level of effort maximizes their returns from fishing. But to do this the manager must be able to infer the value of θ by direct observation as in (i) or indirectly by observing D and E as in (ii).

An example illustrating Result 1 is the following. Suppose that the returns from fishing are random because of observable fluctuations in the market price of fish. Then, one way to introduce the optimal payment schedule $P^*(\theta)$ is through a price support system. According to Result 1, fishermen will supply E* when confronted with the schedule $P^*(\theta)$. Then under the optimal lease agreement, net income received by the fishermen is

$$Z(\theta) = (\theta - r)\, q(E^*) + C(E^*) - P^*(\theta) = \overline{Z} \qquad (8)$$

where θ equals the market price, r is the price of a certificate, $q(E^*)$ is the catch, $C(E^*)$ is the cost of effort, and $P^*(\theta)$ is the payment. Solving for $P^*(\theta)$ in terms of $\overline{Z}$ from (8) we derive

$$P^*(\theta) = q(E^*)(\theta - \overline{\theta}) \qquad (9)$$

where $\overline{\theta}$ is a constant equal to $(C(E^*) - rq(E^*) - \overline{Z})/q(E^*)$. In equation (9) the quantity $(\theta - \overline{\theta})$ can be interpreted as a net price support. Whenever price exceeds $\overline{\theta}$ the fishermen are required to pay the government a tax of $(\theta - \overline{\theta})$ for each unit of the resource sold, whereas the fishermen receive a unit subsidy of $(\bar{\theta}-\theta)$ for each unit whenever price is less than $\bar{\theta}$. Total revenues including net transfer payments $P^*(\theta)$ are

$$q(E^*)\,\theta + P^*(\theta) = q(E^*)\,\bar{\theta} \qquad (10)$$

Thus under the price support system, total revenues accruing to the fishermen are guaranteed by the manager to be equal to $q(E^*)\bar{\theta}$.

The conditions for Result 1 to hold are rather strong. Usually, the manager can not observe E or θ, in which case payments can only be based on D. Unfortunately in this instance it is not possible for the manager to utilize optimal lease agreements and to induce efficient behavior from the fishermen. Work incentive problems arise when payments are based on D, and we can predict under a general set of conditions how this will bias the fishermen's choice of E.

In the analysis remaining we assume that W_θ and D_θ are both positive. We shall specify that $D(E,\theta)$ is a cost (benefit) accruing to the fishermen from the effort allocation E whenever $D_E < 0(>0)$. Since $D_\theta > 0$ we can solve for θ as a function of D and E obtaining

$$\theta = h(E,D) \qquad (11)$$

Define $\tilde{P}(D) = P^*(h(E^*,D))$ to be the optimal payment schedule expressed as a function of D (instead of θ) where $E = E^*$. We then have:

Result 2 If the manager can only observe D, the firm will choose $E(P) > E^*$ $(E(P) < E^*)$ for $D_E < 0$ $(D_E > 0)$ when confronted with the optimal payment schedule $\tilde{P}(D)$.

The proof of Result 2 is contained in APPENDIX B. The interpretation of Result 2 is that when, because of incomplete information, payments must be based on only a portion of the payoff, this introduces diverse incentives for the fishermen and manager. When $D_E > 0$ payments are based only on the revenues generated from fishing, thus the manager shares some of the benefits, but none of the costs of fishing. The fishermen have a disutility for supplying effort, while the manager does not, and consequently the firm chooses an E which is less than optimal. On the other hand suppose the manager can observe the costs of fishing (say by counting the number of boat days expended) but that some of the revenues generated by the boat are hidden. Perhaps fishermen make incidental catches of other species which cannot be monitored by the manager. In this case $D_E < 0$, and payments will take the form of a cost sharing arrangement between the manager and the firm. In this case, the manager subsidizes the fishing operation while the firm retains all the benefits. Predictably, this will encourage excessive expenditures on effort by the fishermen.

3.4 Second Best Contracts

The results of the previous section suggest that the conditions under which the manager can enforce an optimal contract with the fishermen are not likely to occur. In any fishery the manager will have limited ability to observe all the random factors (which we assume are embodied in θ) that affect fishing, nor will it be possible to exactly monitor the effort E supplied by the fishermen. Consequently, it will be necessary to have payments based only on observation of D. Result 2 indicates the kinds of inefficiencies that will occur whenever the boat is confronted with the optimal contract schedule $\tilde{P}(D)$. Consequently, one needs to consider second best contracts in which the self maximizing behavior of the fishermen in choosing efforts is accounted for in constructing payment schedules.

The fishermen's behavior will be shaped by the payment schedule they face. Given any P(D), the fishermen will choose an effort level E(P(D)) depending on the schedule to maximize U^f. One approach for constructing second best contracts is for the manager to choose a payment schedule that maximizes U^f knowing that the fishermen will supply E(P(D)).[8] Another approach is for the manager to acquire additional information about the fishermen's behavior by monitoring other variables besides D. Payments would then be made contingent on the results of monitoring and the inferences that can be drawn about the fishermen's behavior.[9] For example, the manager might monitor the number of days at sea spent by a particular boat, in order to obtain an imperfect estimate of the amount of effort supplied by that boat.

In this section we consider a procedure which uses observations on $D(E,\theta)$ to make inferences about the amount of effort being supplied by the fishermen. To see how this procedure works, first note that the observed payoff $D(E,\theta)$ provides statistical information to the manager about the value of E chosen by the fishermen. Then for an observed value of D, we can represent the conditional distribution for E, denoted by g(E/D) as

$$g(E/D) = f(h(E,D))\,|h_E| \qquad (12)$$

The distribution function g( ) indicates to the manager what the relative likelihood is that the fishermen have supplied certain levels of effort, based on observations of D. Payments are then made contingent on whether the observation reveals the fishermen's effort level to be acceptable or unacceptable to the manager. For example, suppose D is the value of the catch obtained from fishing and that $D_E > 0$. Then if D is unusually high (low) it is quite likely that the fishermen are shirking (working diligently) in which case they are penalized (paid a bonus) by the manager. A penalty (bonus) is a positive (negative) lump sum payment from the fishermen to the manager. We will refer to contracts incorporating these bonus and penalties payments, that are contingent on the observed values of D, as bonus-penalty leases.

In the following material we will consider contracts which utilize bonuses, noting that the development is similar for leases with penalty payments. To make the analysis more concrete and to simplify the exposition we restrict our attention to the case where $D_E > 0$, $D_{E\theta} > 0$ (E and θ are complementary inputs in production), $C = C(E)$ and $C_E < 0$. The case considered here corresponds to a situation in which the manager can observe the revenues generated from fishing, but he cannot observe the amount of effort E, or the cost of supplying it, C(E). The development of results for other cases should be apparent.

The bonus contract, denoted by $B(\hat{D},\pi)$ involves a payment schedule of the following form

$$B(\hat{D},\pi) = \begin{cases} P(D) & D \leq \hat{D} \\ P(D) - \pi & \text{if } D > \hat{D} \end{cases} \qquad (13)$$

The schedule P(D) is a continuous increasing function of D which allows the boat operator and manager to share the profits and losses from fishing. According to (13) payments are given by P(D) unless D exceeds some upper bound $\hat{D}$, in which case the fishermen receives a rebate bonus payment π. The final income denoted by Z(D) accruing to the fishermen under this scheme is represented in Figure 1.

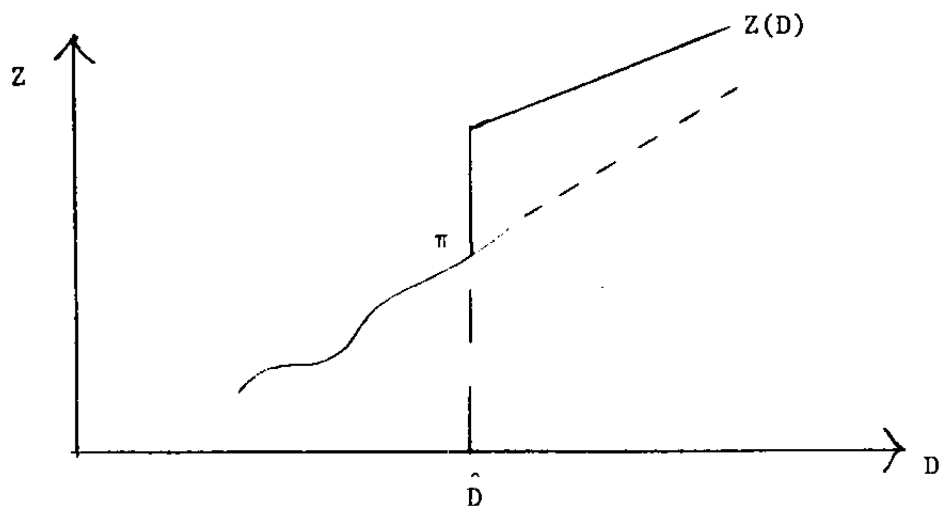

Figure 1
FINAL INCOME UNDER THE BONUS CONTRACT

The incentives for the fishermen to supply effort under the bonus system are clear. Since D increases with E, the firm has an incentive to increase its supply of effort in order to earn the bonus. Thus the natural tendency for the fishermen to shirk, when confronted with a risk sharing contract (see Result 2) can be offset somewhat by the promise of a bonus for good performance. Similar kinds of bonus arrangements are commonly observed in other contexts. For example, salesmen sometimes receive bonuses for sales in excess of some amount. Insurance companies offer vastly reduced (higher) rates to customers with exceptionally good (bad) accident records. Bonus and penalties can be structured so as to provide incentives for agents to act efficiently, and to allow the results of payoff monitoring to be incorporated in the payment schedule.

We can summarize our discussion of bonus-penalty contracts in the following way. Let us express U^f and V, the expected returns to the fisherman and manager, from fishing, as functions of the payment schedule and the effort level supplied by the boats. Given any contract, P(D), the fishermen will choose a level of effort E(P(D)) that maximizes $U^f(P(D), E(P(D))$. Consider the set of second best contracts which does not involve lump sum transfers contingent on the observed value of D. Among these, the contract, denoted by $P^o(D)$ which maximizes $U^f(P(D), E(P(D))$ subject to the fair return constraint in (6) is best. Then we have:

<u>Result 3</u> Given $P^o(D)$ there exists a bonus penalty contract $B(\hat{D},\pi)$ of the form in (13) which dominates $P^o(D)$ in that

$$U^f(B(\hat{D},\pi), E(B)) \geq U^f(P^o(D), E(P^o))$$
$$V(B(\hat{D},\pi), E(B)) > V(P^o(D), E(P^o))$$

The proof of Result 3 appears in APPENDIX C.

Thus given any contract P(D) which does not involve lump sum payments, π, contingent on the observed value of D, we can contruct a contract which does, which is preferrable. That is the bonus contract increases the expected payoff to the manager without decreasing the expected returns to the fishermen as compared to a contract which does not incorporate bonuses. The exact way in which we construct $B(\hat{D}, \pi)$ is discussed and explained in the Appendix. The importance of Result 3 is that it suggests a general form for the second best contract to take.

4. MANAGEMENT OF THE NORTHERN ANCHOVY FISHERY

Two facets of a basic plan for the management of ocean fisheries have now been presented. In Section 2, the certificate-ticket system was proposed in which fishermen would be required to obtain tickets in an amount equalling their total catch for the season. Tickets would be transferable, and given the right conditions, could be traded in a regular market setting. The ticket price would reflect the scarcity value of the fish and the relative abundance of the stock in any season. Such information would provide managers with a feedback mechanism for adjusting quotas in future time periods. It was shown that the issuance of certificates to fishermen would help to insure against the large variations in income between fishermen due to one boat's luck in lacating and catching the fish relative to another's. By controlling the supply and distribution of tickets each season, the manager could limit the catch, restrict inputs used in the fishery, and insure a fair division of the fishery rents among different user groups.

In Section 3, a leasing program was proposed for the government or fishery manager to assist in sharing some of the risks, common to all fishermen. Under the lease, boats would be hired to harvest the resource with the fishermen's wages being made contingent on the value of their catch. Normally, fishing income is uncertain because of variations in stock abundance and market prices. However, this method of payment would, allow for government compensation to be paid to the fishermen in "bad years" in return for a share of the fishermen's income in good years. The form of the payment would depend on the manager ability to monitor the fishermen's actions, and would determine the efficiency and risk sharing properties of the lease.

The practicality of both the leasing and certificates programs will depend on their political feasibility and on the costs of administering and enforcing them. This Section assesses the possibilities for implementing these programs in the management of the northern anchovy fishery. Special attention is given to the administration and enforcement costs, and to the distributional effects of the certificate and leasing systems, as well as how these programs can be expected to solve the management problems peculiar to the northern anchovy fishery. Though the discussion is in terms of a particular fishery, the conclusions we reach should have general applicability.

In addition, these programs are evaluated for their ability to satisfy certain management goals for the anchovy fishery recently established by the Pacific Fishery Management Council in accord with the provisions of the Fishery Conservation and Management Act of 1976 (P.L. 94-265). The Act provides for the conservation and management of fishery resources of the United States by establishing a fishery conservation zone of 200 miles, within which the United States has exclusive management authority over all fishery resources except highly migratory species. Under the Act fishery management plans are to be prepared which form the basis for the determination of annual harvests based on the needs of the states, the fishing industry, recreational groups, consumers, environmental organizations and other interested parties.

We chose to study the Anchovy fishery for the three reasons. First the fishery provides an important source of food and income for consumers and fishermen along the west coasts of Mexico and the United States. Second the yearly income from anchovy fishing varies considerably because of variations in anchovy prices, and the abundance and availability of the stock, consequently the certificate and leasing programs which are designed to reduce the uncertainty of fishermen's income ought to be important for the management of the anchovies. Finally, there is now relatively good data on the fishery from which to make assessments. Much of this information has been recently collected by the Pacific Fishery Management Council in preparing their anchovy management plan.

In the discussion to follow, a history and description of the fishery is first presented in order to uncover certain important management problems for the anchovy fishery. Next, a management plan incorporating the certificate and leasing programs is presented. The probable effect of this plan on the operations in the fishery and the ability of the plan to cope with certain management problems are analyzed. The practicality of the plan, in terms of public acceptance and in terms of administration and enforcement costs are assessed.

The certificate and leasing programs reviewed here differ significantly from management plans proposed by either the California management bodies or the Pacific Fishery Management Council. Our purpose is neither to argue for one plan over another nor to critique the plans offered by the Management Councils, but instead to offer an objective assessment of our proposed certificate and leasing programs for possible use in the management of the northern anchovy fishery.

4.1 History and Description of the Northern Anchovy Fishery

We first provide a physical description of the fishery, and the area where it ranges off the shores of the United States and Mexico. Following this, the various users of the resource consisting of the commercial, bait, and recreation fishermen are identified, and conflicts among the different users regarding the management of the fishery are discussed. Resolving these conflicts is perhaps the major obstacle to successful management of the anchovy. Next, the current economic situation for the commercial anchovy fishery is analyzed with particular attention given to the needs and prospects for controlling access to the fishery, and for eliminating the large fluctuations in fishermen's income caused by variations in stock abundance and market prices.

In describing the fishery, we will uncover the key problems involved in the management of the anchovy. Most of these problems can be resolved reasonably well with the certificate and leasing programs that we have proposed.

4.1.a The anchovy stock and fishery area

The northern anchovy is a pelagic schooling fish found along the west coast of North America. It ranges north from British Columbia south to Baja California, Mexico. The population has been divided into northern, and central and southern subpopulations based on certain biological attributes of the fish.[10] The central subpopulation is the most abundant and economically the most important of the three subpopulations. Thus far management plans for the northern anchovy formulated by the Fishery Management Council have been limited to the central subpopulation, so that our discussion will focus on this subpopulation stock as well.

The central subpopulation extends from approximately 38°N latitude off central California to approximately 30°N off central Baja California, Mexico and out to about 200 miles offshore. Consequently, the central subpopulation is a transboundary stock that will eventually require cooperative management with Mexico. We will have more to say about this in the following Section.

The U.S. fishery for anchovies was originally developed in the early 1950's to fill the void left by the collapse of the California sardine industry. Unfortunately, canned anchovies have never successfully substituted for sardines. Consequently, in 1965 reduction permits for production of fish meal were issured by the California Fish and Game Commission

Besides reduction, anchovies are also utilized for canning, fresh fish for human consumption and live bait. The major portion of the anchovy harvests undergo a reduction into fish meal. Much smaller quantities are utilized as live bait, though anchovies are quite valuable in this use. Quantities for canning and the fresh fish trade are relatively small.

In addition, the anchovy resource found near shore is valuable for the recreational fishing industry as a forage and attractor for larger more desirable fish. Unfortunately, all these various uses for anchovy are not compatible with each other. This is a major problem to contend with in formulating a comprehensive management plan for the fishery.

Description of Different User Groups

The anchovy resource is exploited exclusively by the U.S. and Mexico, with the United States being the larger user. Among domestic fishermen the largest catches at present are taken by the commercial "wetfish" fleet which fishes for reduction purposes. The fleet consists primarly of purse seiners ranging in length from 38 to 100 feet and is basically the remains of the fleet that harvested the sardine, which vanished in 1950. Until 1965, when California began to allow the reduction of anchovies into fish meal, yearly anchovy landings were typically small because of the meager demand for canned or fresh anchovies. Sinch 1965, landings have increased dramatically with 158,511 tons being taken in 1975. In that time the fleet has increased in size, however the basic fleet which catches the majority of the anchovy has remained about the same and approximates 25 vessels.

Besides anchovies, the fleet also fishes for sardines, jack mackerel, Pacific mackerel, bonito, bluefin tuna, and market squid. Of these the anchovy catch accounts for the preponderence of the multi-species harvest. Although the anchovy is the most important of these species for the fleet, management of the anchovy can not be contemplated without considering the other fisheries as well. Policies for managing the anchovy will clearly effect these other fisheries, just as conditions in these fisheries will have an impact on the anchovy industry.

Besides the domestic reduction fishery, there is a domestic live bait fishery which harvests, maintains, and sells small live anchovies to anglers for use as bait and/or chum. The live bait fishery has grown up with the sport fishing industry. Shortly after World War II, the demands for live-bait became sufficient to support a fleet engaged entirely in supplying bait. This fishery is important today because the most valued sport fishes prefer live bait to any other kind. The live bait fleet is very small consisting of only 14 boats. While the live bait catch typically comprises a small percentage of the total anchovy landings, the total value of anchovies used for live bait is quite high.

Live bait operators fish in inshore areas rather than offshore in deeper water. This is because the lampara nets used to catch the bait require a shallow sea-bottom to function effectively. The use of purse sein gear, which works well in deep waters, to catch bait has been unsuccessful because of injuries to the anchovies when the nets are pulled in. Consequently, live bait fishermen are constrained to operate inshore. Reduction fishermen, on the other hand use purse sein gear and operate in deeper water. Consequently, one would expect reduction fishing and live bait fishing to be compatible since the two activities occur in different areas. However bait operators contend that there are difficulties in finding bait because of the reduction fishery; that is, the activities of the reduction fishery prevent the "break-up" of the anchovy stock into small schools which tend to move inshore where they then become available to the bait fishermen. At this time there is no scientific data to verify whether this occurs or not. Nevertheless, these two user groups view themselves as being in direct conflict with each other. Whatever management plan is adopted for the anchovies, it must be sufficiently flexible to placate these two parties.

Recreation fishermen are the third domestic user of the anchovy, though their use of the resource is somewhat indirect. Anchovies are an important source of forage for higher level preditors and prized sports fish, like the barracuda, and yellowtail. To some extent, the apparent importance of anchovies as a food source results from its relative abundance. Sufficient studies have not been completed for determining the extent to which preditors depend exclusivley upon anchovies as a food supply. Nevertheless, recreational fishermen have been particularly concerned with the impact of a large reduction anchovy fishery on their operations. Recently, there has been a trend toward fewer prized game fish and more "last choice" species such as rock-fish, in the catch composition of the prime recreational fishing areas. Recreation fishermen attribute this to the increased activity of the reduction fishery. Also besides competition for the yield of the stock, there is also competition for fishing areas between the two groups.

In summary, there is a conflict among the different domestic user groups. Whether the conflict is real or imagined, is yet to be determined, but the commercial and recreational-bait interests tend to take opposing views. The commercial fishermen perceive that the anchovies are so plentiful that the commercial harvests cannot possibly affect the availability of anchovy for bait and forage. The recreation and bait fishermen, on the other hand, believe that the size of the commercial harvest is crucial in determining availability of bait and the abundance of highly-prized game fish. The truth to the matter is still to be determined, but whatever management plan is adopted it must somehow reconcile these two opposing views.

Besides the United States, Mexico is the other major user of the anchovy resource. Historically, Mexico's interest in the fishery has been small. Recently, however, Mexico has increased its commercial fleet and intends to further develop her fisheries in the future. Because of this, a potential conflict over the international sharing of the anchovies between Mexico and the U.S. could arise. Clearly, a joint fishery management agreement between the two countries will be required if the anchovy resource is to be exploited rationally. However, even in cooperative environment, conflicts in management strategies among the two countries are likely to arise because of differences in the social rate of discount, fishing effort costs, and consumer tastes within the United States and Mexico.[11]

Summarizing the preceeding discussion, we have identified several potential problems for management of the northern anchovy fishery. First there is the jurisdiction problem of how the resource is to be shared and jointly managed by the United States and Mexico. Second is the resolution of conflicts between commercial and recreational interests in the United States.

4.1.b Current Economic Conditions in the U.S. Reduction Fishery

The material presented here describes the economics of anchovies from the commercial fishermen's point of view. Special emphasis is given to analyzing the factors affecting the income of reduction fishermen. The economics of the live-bait and recreational sectors of the fishery are not discussed here because of a lack of data. Nevertheless, in analyzing the reduction fishery we will point out certain management problems that apply to the recreational sectors as well.

The most striking thing one notices about the commercial anchovy fishery is the tremendous variation in fishermen's income that occur from one year to the next. Table 1 gives the average, median, and range of annual earning per vessel in the reduction fishery from 1972-1975. The fluctuations in income are due to variations in the

TABLE 1

AVERAGE, MEDIAN AND RANGE OF ANNUAL EARNINGS PER VESSEL

(expressed in 1977 dollars)

	1972	1973	1974	1975
RANGE	$51-237	$148-589	$52-458	$47-595
AVERAGE	97	285	120	166
MEDIAN	84	274	96	137

[Source: Table 3.2-6 in Combs (1977)]

ex vessel price for anchovy and to the fluctuations in the abundance and availability of the stock. These factors are analyzed in turn.

Anchovy Prices

The major use for anchovy is in fishery industrial production. These products consist of meal, oil and solubles. The meal produced from anchovies is typically 65% protein. The oil and residual liquids are separated and the oil sold in competition with other similar oils. The residual liquid is evaporated to produce a 40 percent solution containing about 30 percent protein and is sold as fish solubles.

By agreement between the Fishermen's Cooperative Association of San Pedro, and the major buyers of anchovy for reduction, the exvessel price for anchovy is tied directly to the established market price for protein. Because the output of anchovy reduction plants in California is small in comparison to that of other domestic and foreign suppliers of protein, the prices paid for anchovy are at the mercy of the national and world wide market. The success or failure of the Peruvian anchovy harvest, for example, can have a profound influence on the domestic demand for California anchovy. As a result of the pricing arrangement and the great variability in the protein meal markets, anchovy exvessel prices fluctuate greatly (see Table 2).

Anchovy Landings

Total landings for the commercial fleet also vary appreciably in successive years. The average, median, and range of annual landings per vessel for years 1972-1975 are recorded in Table 3. Two factors,

TABLE 2

AVERAGE EX VESSEL PRICE PER TON OF ANCHOVY

(expressed in 1977 dollars)

Year		Price per ton
	1972	$39
	1973	71
	1974	49
	1975	34

[Source: Table 3.2-7 in Combs (1977)]

TABLE 3

AVERAGE, MEDIAN AND RANGE OF ANNUAL LANDINGS PER VESSEL

pounds in thousands

	1972	1973	1974	1975
RANGE	2,625-12,339	4,190-16,700	2,102-18,312	2,690-34,115
AVERAGE	5,019	8,062	4,802	9,557
MEDIAN	4,357	7,767	3,863	7,903

[Source: Table 3.2-6 in Combs (1977)]

the abundance, and the availability of the stock have an important effect on anchovy landings in the commercial as well as live bait sectors of the fishery each season. The abundance or biomass of the stock is highly variable. The spawning biomass estimates are the best available estimates of the anchovy biomass. The observed population levels regularly deviate from the expected values of the estimated population growth curve by as much as 50 percent.[12] Infact, fluctuations in the anchovy stock are so great, that the maximum sustained yield concept (the practice of maximizing the sustainable harvest from a population) which is frequently used as a management goal in other fisheries is not considered by the Management Council to be meaningful in the context of the anchovy.

The availability or catchability of the stock can also vary within a year and between years. Several factors contribute to this: high winds and waves or a bright moon create difficult conditions for fishers, and the reduction fishery often halts entirely when conditions are poor. At other times the fish may not be sufficiently concentrated in surface schools to allow good fishing. This can occur even when other conditions are satisfactory.

The random movements in the price for anchovies and the variations in fishing condition that occur are factors affecting income which are beyond the fishermen's control. Given the current situation and institutions in the fishery, there are but a few things fishermen can do to hedge against or to reduce yearly income fluctuations. The share remuneration system is one way that the boat owners and fishermen can share some of the risk costs of fishing. The system, which is widely used in fishing allows crewmen and vessel owners to share in the profits and losses from fishing. When vessels are extremely successful, the crew shares the profit by receiving payments over and above the minimum amount needed to secure its services. Conversely, when fishing is very poor, the crew bears much of the financial burden through lower payments. Another way for vessel owners and fishermen to avoid large losses when conditions in the anchovy fishery are bad is to switch from fishing for anchovies to fishing for another species like jack mackerel. Unfortunately, conditions across related fisheries are often correlated, so that a switch in fishing for one species to another may offer little relief for the fishermen.

Currently, vessel owners and crewmen bear all the risks associated with harvesting the anchovies. Thus a major obstacle to the successful management of the anchovy is the problem of providing adequate risk sharing. Institutions are needed which allow the risks of fishing to be spread more evenly among the fishermen and the management body or government.

4.2 A Certificate and Leasing Program for Management of The Northern Anchovy Fishery

The program will be evaluated in terms of its cost of administration and enforcement and in terms of its ability to solve the key management problems mentioned in the previous pages as well as its ability to satisfy the management goals set forth by the Fishery Management Council. In summary, we would like an anchovy management plan that

(1) provides an optimum yield from the central subpopulation of the northern anchovy within the United States' Fishery Conservation Zone, and waters under Mexican jurisdiction

(2) resolves conflicts between U.S. commercial and recreational interests

(3) provides efficient, cost minimizing utilization of the northern anchovy stock

(4) provides for the government sharing of risks with the fishermen

Determination of the optimal yield from the fishery to satisfy the interests of the United States and Mexico is an extremely difficult problem. The two countries are likely to have different preferences for, and conceptions of, how to best utilize the anchovy stock on a continuing basis. The presence of extreme uncertainties about the natural growth of the population and the depletion of the stock due to fishing will further complicate the problem. These considerations are beyond the scope of this study. Subsequently we shall assume that the allowable yield each season is determined in some fashion jointly by the United States and Mexico.

We now turn to a description of our proposed certificate plan for allocating quotas among different users.

4.2.a Certificate-Ticket Program

The theory of managing with the certificate system was discussed in Section 2 so that we can turn directly to evaluating the plan for use in the anchovy fishery.

Allocation of Certificates and the Division of Rents in the Anchovy Fishery

Under the program, ownership rights to shares of the quota in the form of stock certificates are allocated to the United States and Mexico, and within the U.S. to the various domestic users. Each certificate entitles the owner to the rights to a fraction of each seasonal quota. Certificates are transferable to allow trade between the two countries and among individual users. Of course, the actual allocation of certificates is crucial because the rents earned in the fishery will be captured by the certificate holders. Any proposed distribution of certificates will be controversial, since one party's gain will be another party's loss when the number of rights to be allocated are fixed.

One can think of several criteria for dividing the quota between the United States and Mexico. An allocation of rights based on historical fishing records would benefit the United States since it has been the predominant user of the resource. However, a more nearly equal distribution of certificates might be warranted in view of Mexico's plans to increase its anchovy reduction fishery. The allotment of certificates to each country could also be made to change over time if the situation warranted it.

Since certificates can be traded, one country could increase its share of the fishing rights by purchasing certificates from the other country. One possibility would be for the United States to purchase all of Mexico's certificates in order to become the sole owner of the anchovy fishery. This would eliminate the need for joint agreement between the two countries in the management of the fishery. On the other hand, other countries might acquire rights to the fishery by purchasing certificates from either the United States, or Mexico. Infact, if the rights to various fisheries could be traded among different countries, this would allow countries to spread their risks by diversifying their ownership of fishery resources. Although the plan is tempting, it would be impractical because of the difficulty of getting large numbers of countries with diverse interests to reach agreement on a common management strategy for each fishery.

It is important to emphasize that the certificate holders collect the rent from the fishery, whether they use the tickets from the certificates themselves for fishing, or sell the tickets to someone else. This means that there is a clear separation between fishing and the collection of rent. Consequently once the certificates are allocated there is no incentive for a country to expand its fleet for purposes of capturing a larger share of the total fishery rents. This eliminates over capacity in the fishery and the need for entry restrictions.

There will be a major cost to administering the certificate program to ensure that the total catch of all domestic users within each country does not exceed the country's share of the quota. On site inspection at each of the U.S. and Mexican ports will be required to monitor landings. Of course any management by quota program will require monitoring of some sort.

The U.S. share of certificates will be allocated among commercial and live bait fishermen, processors, and the government, or public at large. The distribution of fishery rents will be determined by this allocation, so that any proposal for issuing certificates will be closely scrutinized by the various fishery interests. One method for distributing rights in the fishery, which appears to coincide with the spirit of the Extended Jurisdiction legislation, would be to distribute certificates to individual fishermen in proportion to the extent that they have relied on the fishery for income. Numerous other allocation criteria exist, some of which were discussed in Section 2.

The conflict between the live bait and reduction fishermen over the use of the anchovy is really only a manifestation of the competition of the two groups for their share of the fishery rents. The allocation of certificates will determine each group's share of the rents independent of how the anchovy resource is utilized. As we will explain shortly in the next section, when rights to harvest the resource are transferable, the resource will be utilized in highest marginal value use. Thus, even if all of the quota should be used for reduction, bait fishermen will still receive their share of the rents by selling their excess fishing rights for the season to the commercial fishermen.

The Fish Ticket Market: A Device to Minimize Rising Costs, Disperse Risks, and Allocate the Anchovy Among Different Uses

How the Market Works

At the beginning of each season, each certificate holder is issued a specified number of fish tickets. The holder of a fish ticket is allowed to catch a fixed amount of fish. Tickets are bought and sold in a market which is set up and run by the fishery manager. The fishermen must present the appropriate number of tickets to the managing authority when they go to sell their catch. To acquire tickets, the fisherman can either purchase them from a certificate holder or, if he owns certificates himself, simply use the tickets he has received.

There would be certain administrative costs to the manager in setting up the ticket market, and in collecting tickets from the fishermen upon the sale of their catch. Since there are already procedures established for monitoring catches in order to provide biologists with information for making anchovy stock assessments, the extra cost of ticket collection would be small.

Who Gets to Fish

If there were crowding externalities in the fishery the number of boats would be restricted through a licensing procedure in order to avoid congestion. In the absence of crowding externalities, restricting the number of fishermen would be unnecessary. Any vessel would be allowed to fish if it acquired the necessary fish tickets to cover its catch. If this free entry policy were implemented, the number of boats operating in the fishery would not be excessive. This is because fishermen would be paying the full costs to fish, including the user's charge for the resource that would be captured in the price of a fish ticket. Note that although there would be no economic reasons to exclude foreign operators from the fishery, there might be considerable political pressure from domestic fishermen to exclude them, particularly if foreign vessels were more efficient than domestic boats. At present there is little interest among foreign countries in fishing for the northern anchovy.

Utilization of the Anchovy

The market for fish tickets is not only a device for allocating harvesting rights, but it also serves to drive the anchovy resource into its highest marginal value use. The rights to harvest the resource are a scarce commodity that fishermen bid for via the market for fish tickets. The fishermen receiving the greatest value for their catches can afford to bid the highest prices for the harvesting rights. As long as market prices for the anchovy are indicative of its social value in its various uses, as live bait or fish meal, allocation of the resource between these uses will be socially efficient. If this is true, the management of the fishery is considerably simplified. The closing of areas and seasons to reduction fishing in order to insure an adequate live bait fishery becomes unnecessary under the ticket plan. If anchovy is really valuable as live bait, then live bait operators can insure themselves of an adequate supply of anchovy by bidding away harvest rights from the reduction fishermen.

Recall from Section 4.1.b that the live bait operators claim that the commercial fishing process causes their costs to rise. If this is true, it constitutes a type of crowding externality which probably will require that reduction fishermen be restricted from fishing in areas where they will affect the live bait fishery.

Sports fishermen benefit from having large anchovy stocks available as forage for prized game fish like the barracuda and yellowtail. Ideally, the quota set each season by the manager is small enough so as to leave sufficient forage for valuable sports fish to feed on. However if recreational fishermen felt the quota was to high, they could purchase fish tickets themselves without using them in order to reduce the total catch. The problem with this suggestion is that the availability of anchovy for forage is a public good enjoyed by all recreational fishermen. Acting individually, fishermen would purchase less than the efficient amount of tickets because of the "free rider" effect. That is, individual operators would hesitate to purchase tickets thinking that they could benefit from a catch reduction at no cost to themselves by allowing other fishermen to purchase the tickets. Thus a cooperative effort among all recreational fishermen would be required to affect the right purchase of tickets.

Cost Minimizing Properties of the Certificate-Ticket Plan

The certificate-ticket plan promotes least cost fishing. Because fishermen pay the full costs of fishing under the plan, incentives to over fish are eliminated. Consequently, no inefficient techniques need to be used, and no efficient techniques are barred from being used in order to restrict fishing inputs and reduce fishing pressure on the stock.

The ticket market will function to lower total fishing cost. Unrestrained competition among the anchovy fishery will also serve to lower total fishing costs. This is because efficient fishermen will be able to pay a higher price for fish tickets. Hence, more efficient fishermen will displace inefficient fishermen resulting in lower total fishing costs.

Risk Sharing Properties of the Certificate-Ticket Plan

Fishermen's income may vary simply because of the "luck of the draw". During a season, some fishermen will be fortunate in locating anchovy schools, while others will be unlucky in their effort to land fish. Considerable smoothing of variations in fishermen's income should be achieved with the ticket market. Fishermen having a good season can purchase more tickets than their own certificates entitle them to, whereas fishermen having a bad season can reduce their losses by selling tickets they have either previously purchased or have obtained by holding certificates.

4.2.b Leasing Contracts

Anchovy fishermen experience large fluctuations in income due to seasonal variations in stock abundance, in fishing conditions, and in the market demand for the resource. Previously we discussed how the certificate-ticket system can help to smooth out the variations in income resulting from the good and bad luck a fishermen experiences during the season. However the risks associated with changes in price and with variations in the stock abundance which affect all fishermen simultaneously, can not be alleviated by the trade of fish tickets. Currently, the only institution providing for the spreading of common risks within the fishery is the share remuneration system whereby crewmembers and boat owners share in the profits and losses from fishing with each other. Despite the government's superior capability to disperse risk through pooling and diversification fishermen now incur all of the risks themselves. Our proposed leasing plan provides a means for the government to share some of the risks involved in fishing with the boat owners and crewmembers. The theory of leasing was presented in Section 3; we now turn to a discussion of leasing in the northern anchovy fishery.

How the Lease Contract Works

The leasing system is intended to be used in conjunction with the certificate-ticket plan. The allocation of certificates and the running of the ticket market by the fishery manager serve to distribute the rents generated by fishing, and to direct the anchovy resource into its highest marginal value use. The leasing system is designed to provide relief to the commercial and live bait boat owners in bearing the risks associated with fishing.

Under the lease the government and the boat owner agree to a payment plan whereby both parties share in the profits and losses from fishing. As before, the fishermen acquire the rights to fish by purchasing fish tickets. The price of the tickets is calculated as part of the boat's fishing costs. At the end of the season the net income earned by the boat is computed, and payments between the government and the boat owner are made depending on the net income earned by the fishermen. If the net income were low, the vessel operator would be compensated in the form of a government transfer payment. On the other hand if fishing had been "good" the government would be then entitled to a share of the profits generated by the boat. In essence the risk sharing agreement with the government would allow the fishermen to hedge against the possibility of a low income year by sharing profits with the government in a high income year.

The risk sharing options provided by the lease would be particularly important for operators in the anchovy fishery. Under the recently approved Fishery Management Plan the allowable catch quotas set each season will vary directly with the current estimated spawning biomass. The natural growth of the anchovy stock is highly variable, so that the Management Council must be very careful in setting quotas. Under the various plans considered by the Council for setting quotas, the commercial anchovy fishermen may be excluded entirely from fishing from 5 to 30 percent of the seasons.[13] While this seems to be an extreme measure for the Council to take, it is necessary to avoid the possibility of severely depleting the anchovy population. If the commercial fishermen were to be excluded from the fishery during a given season, under the leasing program, fishermen would receive compensation from the government for losses suffered during the closed season. The current Fishery Management Plan does not provide for such compensation.

On average, between making transfer payments and collecting profit shares, the government would expect to earn a slight positive return from leasing. The net revenues collected by the government would be used to administer and enforce the leasing program as well as to conduct research on current and future status of the anchovy stock.

Under normal circumstances there would be no restriction on the number of boats operating under the lease system. The allocation of fishing rights through the ticket market would serve to prevent over capitalization and over fishing. On the other hand, the leasing program could be used to restrict the number of boats in the fishery and to regulate fishing activities, if crowding externalities were to occur. The lease would then also serve as a license for boats to operate in the fishery. The lease specifications would include the rights granted to the boat (fishing duration, gear to be used, area to be fished) as well as the payments agreement between the government and the fishermen for risk sharing purposes.

Form of the Payment Schedule

Under ideal circumstances, all the uncertainty costs of fishing would be born by the government because its superior capacity for pooling and spreading risks. In this case, fishermen would receive a fixed income independent of the value of their catch. For example, if the market price for anchovy were to fall, the government would compensate the fishermen for any losses incurred. On the other hand, any windfall profits earned by fishermen due to unexpected high prices or catch rates would be turned over to the government.

However, as we explained in Section 3, the problem with guaranteeing fishermen's income is that it increases their incentives to shirk, or to supply less than the full amount of effort in fishing. In the anchovy fishery, boat operators would be induced to direct effort towards the catch other species like the jack mackerel, if anchovy incomes were guaranteed. Assuming the government could monitor the fishermen's behavior, this incentives problem could be overcome by penalizing the boats whenever they supplied less than the full amount of effort. In reality, though, its impossible to directly observe a boat's effective production of effort. An indirect way to measure effort is by the size of the anchovy catch. The size of the catch is determined jointly by the amount of effort supplied and by the fishing conditions at the time of the catch. If the conditions at the time of fishing are known exactly, then one can accurately calculate the amount of effort the fishermen supply by monitoring their catch. Unfortunately though, fishing conditions are highly variable, so that it is difficult to make accurate estimates of effort supply from catch data.

To alleviate incentive problems while retaining some degree of the risk sharing fishermen would be paid according to a bonus contract. Under the contract, fishermen's final income, after transfer payments, would be made contingent on the value of their catch. There would be partial sharing of losses and profits with the government, but now fishermen's income would be directly tied to their success in catching anchovies. An abnormally large harvest would be rewarded with a bonus payment by the government as added incentive for the boats to fish efficiently.

Costs of Enforcement

In order to effectively implement the leasing plan it will be necessary to adopt some enforcement procedures. Since transfer payments are based on the boat's reported revenues the major enforcement costs will be taken up with monitoring the anchovy revenues received by the fishermen. This should be relatively easy to do since good and accurate records of their landings are already kept by the processors and the California Department of Fish and Game. As we mentioned before it is also necessary to monitor landings in order to make periodic assessments of the anchovy stock, and to administer the certificate-ticket program.

If the lease is also used to limit the number of vessels in the fishery or to regulate fishing by seasons, area, gear type, or composition of catch then the enforcement procedure will be considerably complicated. In this case it will be necessary to provide air and sea surveillance of the vessels to assure compliance with the seasons and area closures. On-shore inspection of the boats will also be necessary to insure that only licensed vessels are landing anchovies, to check the composition of the catch, and to insure that the proper type of gear is being used. Of course these enforcement measures would be necessary in order to implement any program calling for these types of fishing regulations.

Public Acceptance and Political Feasibility

Under the lease program, the manager relieves the fishermen of some of their risk bearing costs, and thus such a program ought to be popular among the vessel owners, and crewmembers. The plan would seem to be politically feasible since there is a precedent for government risk sharing programs in other resource industries as exemplified by the royalty system used for the leasing and development of oil, natural gas, and mineral resources. Infact, a type of leasing arrangement between boat owners and crewmembers has existed for years in the form of the share remuneration system. In essence, the proposed lease program would expand current provisions for risk spreading in the fishery by making the government a risk sharing partner of the fishermen.

5. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The recent passage of the Extended Jurisdiction legislation by numerous countries has prompted us and other researchers to re-evaluate current fishery management programs. The legislation provides the legal framework for the United States and other countries to retain exclusive control over the use of their marine resources. Thus the United States can now attend to certain problems that have historically plagued management programs. The first of these involves the common property status of ocean fisheries that has led to over-exploitation of fishery resources and excessive capitalization in the fishing industry. The second deficiency involves the lack of public institutions to share the risks of fishing with the boat owners and crewmen. Despite the government's superior capability to minimize risk costs, the adverse impacts of economic uncertainty in the fishery now fall entirely on the fishermen. In this report a two-part, certificate-leasing program designed to alleviate these two problems is presented and evaluated for possible use in the northern anchovy fishery.

5.1. Certificate Ticket Plan

The certificate-ticket system creates property rights in the resource that are distributed in the form of stock certificates to various users. The system relies on the use of a market in fish tickets to determine resource use. The total seasonal catch is limited by the number of fish tickets supplied to certificate holders by the manager. Competition among fishermen for these tickets drives the less efficient operators from the fishery, and directs the fishery resource into its highest marginal valued use. The beauty of the market is that it creates a separation between the effort a fisherman exerts and the amount of rent he received as a certificate holder. The share of the rent accruing to a fisherman is determined by his allocation of certificates and not by his own utilization of the resource. This eliminates his incentives to over-fish. Also, long run adjustments by the fishing industry to circumvent quotas are less likely to occur. Other features of the plan which make it attractive for use in the northern anchovy fishery are its ease of enforcement, smoothing of variations in fishermen's income, and its ability to control relative efforts in multispecies fisheries.

The ticket market is also valuable for another reason. The price of tickets provides information as to the relative abundance of the stock, prevailing fishing conditions, and the market value of the fish. For example, high ticket prices indicate that current fishing conditions are good, or that the market demand for fish is high. High prices may also tell the manager that the seasonal quota has been set too low. The ways the manager can use this information for adjusting quotas and for updating information on stock conditions was briefly mentioned in Section 2 and is an important area for future research.

The main difficulty in implementing the certificate-ticket plan is to decide how to allocate certificates among different users. Since the rent from the fishery is received by the stock holders, any certificate distribution is likely to be controversial. In the northern anchovy fishery the resource rents must be divided between two countries, Mexico and the United States, and within each country between the commercial and recreational fishermen, processors and the public at large. One possibility is to allocate rent shares according to one's historical use and dependence on the resource. This would favor the United States and would, therefore, be challenged by Mexico unless each country's share was calculated by taking into account the planned increase by Mexico of her reduction fishery. Numerous other procedures and doctrines for dividing up the returns from the fishery have been proposed. These need to be evaluated in terms of how equitable and fair they are and in terms of their economic impact on various user groups. Another related issue deserving further study is the question of how the United States and Mexico can jointly manage the transboundary anchovy stock. Differences between the countries in the social rate of discount, in the cost of fishing, and in consumer tastes will probably cause conflicts in management strategies, even under the best of circumstances.

5.2. Leasing Plan

Under the leasing system, variations in the fishermen's income are reduced by making the government a risk sharing partner of the fishermen. This plan could provide needed relief for anchovy fishermen whose income varies tremendously due to fluctuations in the stock and in anchovy prices.

One problem with the lease is that in the process of insuring the fishermen against variations in income, the manager may reduce their incentive to harvest the resource. This can be overcome if the manager can observe the actions of the fishermen and can make payments to them contingent on their supplying adequate effort. Otherwise, if effort cannot be directly observed, a system of bonus and penalty payments for rewarding (penalizing) the fishermen whenever catches are abnormally large (small) can be used to maintain work incentives.

Our analysis of leasing has abstracted from certain complexities that should be investigated further. We assumed that the manager and the fishermen have the same information about the fishing conditions. Conceivably, though, the fishermen might know more about the conditions of the stock than the manager. In this case, the manager must construct a lease to take these information differences into account. For example, the lease should be flexible enough so that if fishermen observe that fishing conditions are poor they can decrease their supply of effort. Naturally, though, because the fishermen have better information about the true fishing conditions, it will be difficult for the manager to regulate their activities while maintaining flexibility in the lease. Related to this problem is the issue of how the manager can use the lease to solicit and process information from the fishermen for updating stock assessments and for making adjustments in management strategy.

APPENDICES

In the mathematical analysis to follow we will use the following basic assumptions, some of which have been introduced already in Section 3.

Assumption 1: The functions $W(E,\theta)$, $D(E,\theta)$ and $C(E,\theta)$ are continuously twice differentiable and concave.

Assumption 2: There exists a finite maximum rate E_{max} at which effort can be supplied so that $E \in [0,E_{max}]$

Assumption 3: The probability density function for θ is given by $f(\theta)$ which is strictly positive and continuously twice differentiable for $\theta \in (\underline{\theta},\overline{\theta})$. In addition we also require that (a) $\lim_{\theta \uparrow \overline{\theta}} f(\theta) > 0$ or (b) $\lim_{\theta \uparrow \overline{\theta}} f(\theta) = 0$ and the left-hand derivative at $\overline{\theta}$, $f'_-(\overline{\theta})$ is strictly negative.

Additional assumptions will be introduced as they are needed.

APPENDIX A

NECESSARY AND SUFFICIENT CONDITIONS FOR AN OPTIMAL CONTRACT

Assuming it exists, the optimal contract is determined as the solution to the problem

$$\max_{P(\theta),E} \quad V[Z(\theta)] \tag{A1}$$

subject to (6), where $Z(\theta)$ is defined in (4). Employing standard variational techniques and assuming a unique interior solution to (A1) we obtain the necessary first order conditions:

$$u^{f'}[Z(\theta)] - \lambda = 0, \ \forall\theta \tag{A2}$$

$$E_\theta \ u^{f'}[Z(\theta)] \ Z_E(\theta) - \lambda E_\theta \ P'D_E = 0 \tag{A3}$$

where λ is the Lagrange multiplier corresponding to the constraint in (6). Condition (A2) implies that $Z(\theta)$ is constant for all θ, and substituting (A2) into (A3) yields the condition $E_\theta \ W_E = 0$. Assuming $W(E,\theta)$ and u^f are concave insures that the necessary conditions (A2) and (A3) are also sufficient for the maximization in (A1).

APPENDIX B

PROOF OF RESULT 2

Assume W_θ and D_θ are both positive. Given a schedule $P(D)$, fishermen choose effort $E(P(D))$ from the feasible set $[0,E_{max}]$ to maximize $U^f[Z(\hat{\theta})]$. A maximum exists assuming U^f is continuous in E. Assuming a unique interior solution to the maximization, we obtain the condition:

$$E_\theta \; u^{f'} \; Z_E = 0 \tag{B1}$$

To prove Result 2 it suffices for us to show that the equality in (B1) holds for $E(\tilde{P}(D)) > (<) \; E^*$ as $D_E < (>) \; 0$, where $\tilde{P}(D) = P^*(h(E^*,D))$. Define $\Phi(E) = E_\theta \; u^{f'} \; W_E$ and note $\Phi(E^*) = 0$ by (A1) and (A2). Differentiating Φ yields

$$\Phi'(E) = E_\theta[u^{f''}(1-\tilde{P}')^2 \; W_E{}^2 + u^{f'} \; W_{EE}] < 0 \tag{B2}$$

where $\tilde{P}' = P^{*\prime} \; h_D = \dfrac{W_\theta}{D_\theta} > 0$.

Rewriting $E_\theta \; u^{f'} \; Z_E$ in terms of $\Phi(E)$ we obtain

$$E_\theta \; u^{f'} \; Z_E(E^*,\theta) = \Phi(E^*) + E_\theta \; u^{f'} \; (-\tilde{P}'D_E) \lessgtr 0 \text{ as } D_E \gtrless 0. \tag{B3}$$

Thus (B1)-(B3) imply $E(\tilde{P}) \gtrless E^*$ as $D_E \lessgtr 0$.

APPENDIX C

PROOF OF RESULT 3

To make the analysis more concrete and to simplify the exposition we restrict our attention to the case where W_θ, D_θ, D_E, $D_{\theta E} > 0$, $C = C(E)$ and $C_E < 0$. To further facilitate the proof of Result 3 we introduce the concepts of feasibility and dominance. Let $U^f[P,E] = E_\theta\, u^f[W(E,\theta)-P]$ and $V[P,E] = E_\theta\, P(D(E,\theta))$. A contract and effort level pair $[P(D),E]$ are said to be feasible if $E = E(P)$ and $U^f[P,E(P)] \geq \overline{U}^f$; that is the pair is feasible if the fishermen can be induced to supply E when confronted with P. One pair $[P_1,E_1]$ is said to dominate another $[P_2,E_2]$ if $V[P_1,E_1] > V[P_2,E_2]$ and $U^f[P_1,E_1] \geq U^f[P_2,E_2]$.

The proof of Result 3 is carried out in several steps with a sequence of Lemmas. First we assume there exists a contract-effort pair $[P^o,E(P^o)]$ having the properties that it is feasible, that P^o is the schedule that maximizes $V[P,E(P)]$ for the class of contracts that are continuous and do not involve lump sum bonus or penalty payments, that P^o is continuous twice differentiable and that $E(P^o)$ is unique. The last two assumptions simplify the mathematics, but do not affect the validity of our results. Lemma 1 demonstrates that other continuous contracts $P^\alpha(D)$ can be constructed from $P^o(D)$ such that $[P^\alpha,E(P^o)]$ dominates $[P^o,E(P^o)]$. The problem with using P^α is that $[P^\alpha,E(P^o)]$ is not feasible; that is $E(P^\alpha) \neq E(P^o)$. Lemmas 2-4 then show that there exist bonus contracts $B^\alpha(\hat{D},\pi)$ constructed from P^α such that $[B^\alpha,E(P^o)]$ is feasible and it dominates $[P^o,E(P^o)]$.

It turns out that the construction of P^α and B^α depends on the sign of $V_E[P^o,E(P^o)]$. The most likely possibility, and the case considered here, is $V_E[P^o,E(P^o)] > 0$; that is given the schedule P^o, the manager would like

E to be further increased if he could control it directly. This seems plausible, certainly one does not expect to be able to construct a payment schedule that completely eliminates incentives for fishermen to shirk. However we have been unable to find general assumptions that exclude the possibility that $V_E[P^o, E(P^o)] \leq 0$.[14] This exceptional case is analyzed in Lewis (1977) with basically the same results as are reported here.

To begin with, consider the schedule $P^\alpha = P^o(D) + \alpha h + F(\alpha)$ for $\alpha \varepsilon [0,1]$. Writing $Z = Z(P,E(P))$ as a function of the contract-effort pair, we have $h = E_\theta\ Z(P^o, E(P^o)) - Z(P^o, E)$. The constant $F(\alpha)$ is defined so as to maintain the expected utility of the fishermen at a constant level with $U^f[P^o, E(P^o)] = U^f[P^\alpha, E(P^o)]$ holding effort constant at $E(P^o)$. It is easy to verify that P^α has the same continuity and differentiability properties as P^o. Let $Z^\alpha = (1-\alpha)\ Z\ (P^o, E) + \alpha E_\theta\ Z(P^o, E(P^o)) - F(\alpha)$ be the net income accruing to the fishermen for the pair $[P^\alpha, E]$. Notice that the effect of increasing α is to make the fisherman's income more certain which of course he prefers. Note that $P^\alpha = P^o$ and $Z^\alpha = Z$ for $\alpha = 0$.

<u>Lemma 1</u>: The contract-effort pair $[P^\alpha, E(P^o)]$ dominates $[P^o, E(P^o)]$ for $\alpha \varepsilon (0,1)$, and $dV[P^\alpha, E(P^o)]/d\alpha > 0$.

<u>Proof</u>: One can easily verify that $dV[P^\alpha, (P^o)]/d\alpha = F'(\alpha)$. By construction $F(\alpha)$ is defined so as to satisfy the condition $U^f[P^\alpha, E(P^o)] = U^f[P^o, E(P^o)]$ for $\alpha \varepsilon [0,1]$. Differentiating this expression with respect to α we obtain

$$F'(\alpha) = \frac{E_\theta\ u^{f'}[Z^\alpha(\theta)]h}{E_\theta\ u^{f'}[Z^\alpha(\theta)]} \tag{C1}$$

Since $u^{f''} < 0$ we have

$$u^{f'}[Z^{\alpha}(\theta)] \gtrless u^{f'}[E_{\theta}\, Z(\theta) - F(\alpha)] \text{ for } h \gtrless 0 \tag{C2}$$

which implies

$$F'(\alpha) > \frac{E_{\theta}\, u^{f'}[E_{\theta}\, Z^{\alpha}(\theta)]E_{\theta}\, h}{E_{\theta}\, u^{f'}[Z^{\alpha}(\theta)]} = 0 \tag{C3}$$

Of course $[P^{\alpha},E(P^{o})]$ is not feasible for $\alpha > 0$, otherwise this would contradict our assumption that $[P^{o},E(P^{o})]$ is best among the set of pairs involving continuous contracts. Given $V_E[P^{o},E(P^{o})] > 0$ we can establish that there is a tendency for the fishermen to shirk when confronted with the schedule P^{α}.

<u>Lemma 2</u>: Let $\overline{E}(P^{\alpha}) = \{E(P^{\alpha})\,|\,U^{f}[P^{\alpha},E(P^{\alpha})] \geq U^{f}[P^{\alpha},E];\ E\varepsilon[0,E_{max}]\}$. If $V_E[P^{o},E(P^{o})] > 0$, then $U^{f}_{E}[P^{\alpha},E(P^{o})] < 0$ and $E(P^{\alpha}) < E(P^{o})$, $E(P^{\alpha})\ \varepsilon\ \overline{E}(P^{\alpha})$ for all α small.

<u>Proof</u>:

(i) Suppose there exists a $E(P^{\alpha}) = E(P^{o})$ for some $\alpha > 0$. Then the pair $[P^{\alpha},E(P^{o})]$ is feasible and $[P^{\alpha},E(P^{o})]$ dominates $[P^{o},E(P^{o})]$ by Lemma 1. But this contradicts the assumption that $[P^{o},E(P^{o})]$ is best among feasible continuous contract pairs.

(ii) Suppose there exists a $E(P^{\alpha}) > E(P^{o})$ for all $\alpha\ \varepsilon\ (0,\alpha')$; $\alpha' \leq 1$. Observe that $U^{f}[P^{\alpha},E]$ is continuous in α and E. Consequently $\sup_{E} U^{f}[P^{\alpha},E]$ is a continuous function of α, and $\overline{E}(P^{\alpha})$ is an upper semi-continuous mapping of α into E (see Maximum Thm, Berge, p. 116).

One can verify that $V_E[P^\alpha, E(P^o)]$ is continuous in α and that therefore $V_E[P^\alpha, E(P^o)] > 0$ for α sufficiently small. Since $\bar{E}(P^\alpha)$ is U.S.C. and $\bar{E}(P^o) = \{E(P^o)\}$ is single-valued (by assumption), $|E(P^o) - E(P^\alpha)| \to 0$ as $\alpha \downarrow 0$ for $E(P^\alpha) \in \bar{E}(P^\alpha)$. Consequently there exists a $E(P^\alpha)$ sufficiently close to $E(P^o)$ with $E(P^\alpha) > E(P^o)$ such that

$$\begin{aligned} V[P^\alpha, E(P^\alpha)] &> V[P^\alpha, E(P^o)] > V[P^o, E(P^o)] \\ U^f[P^\alpha, E(P^\alpha)] &> U^f[P^\alpha, E(P^o)] = U^f[P^o, E(P^o)] \end{aligned} \tag{C4}$$

But this violates our assumption about $[P^o, E(P^o)]$. Consequently, $E(P^\alpha) > E(P^o)$ and $U^f_E[P^\alpha, E(P^o)] > 0$ for all α sufficiently small.

According to Lemmas 1 and 2 it is possible to derive contract-effort pairs $[P^\alpha, E(P^o)]$ that dominate $[P^o, E(P^o)]$. Unfortunately, however, such pairs are not feasible. Denote by $B^\alpha(\hat{D}, \pi)$ the bonus contract with payments:

$$B^\alpha(\hat{D}, \pi) = \begin{cases} P^\alpha(D) & \text{if } D < \hat{D} \\ P^\alpha(D) - \pi & \text{if } D \geq \hat{D} \end{cases} \tag{C5}$$

We now show in Lemma 3 that by slightly modifying the P^α schedule to allow for bonus payments we can construct new contract pairs $[B^\alpha(\hat{D}, \pi), E(P^o)]$ which are feasible. The proof of Result 3 is then concluded by showing that such pairs also dominate $[P^o, E(P^o)]$ in Lemma 4.

<u>Lemma 3</u>: Consider the bonus contract $B^\alpha(\hat{D}, \pi)$ where $\hat{D} = D(E(P^o), \hat{\theta})$. Then

(a) For $\lim_{\theta \uparrow \overline{\theta}} f(\theta) > 0$, then $[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta})), E(P^{o})]$ is feasible for all

$(\alpha,\hat{\theta}) \in S(\alpha',\theta') = \{(\alpha,\hat{\theta}) | 0 < \alpha \leq \alpha', \theta' \leq \hat{\theta} < \overline{\theta}\}$

(b) For $\lim_{\theta \uparrow \overline{\theta}} f(\theta) = 0$, and $f'_{-}(\overline{\theta}) < 0$ then there exist continuous functions $\pi(\alpha)$ and $\hat{\theta}(\alpha)$ such that $[B^{\alpha}(\hat{D}(\alpha),\pi(\alpha)), E(P^{o})]$ is feasible, for $\alpha \varepsilon (0,\alpha')$; $\alpha' \leq 1$.

Proof: Only the proof of part (a) is presented here noting that (b) follows by a similar argument. The proof of (a) is accomplished by first showing that the necessary conditions for a maximum of $U^{f}[B^{\alpha}(\hat{D},\pi),E]$ are satisfied at $E(P^{o})$ for all $(\alpha,\hat{\theta}) \in S(\alpha',\theta')$. Then we demonstrate that these necessary conditions for a maximum are also sufficient.

(i) Given our assumptions about B^{α}, P^{α}, W, D, C and $f(\theta)$, $U^{f}[B^{\alpha}(\hat{D},\pi),E]$ is differentiable in E and applying Leibniz's formula for differentiation we obtain

$$U^{f}_{E}[B^{\alpha}(\hat{D},\pi),E] = \underset{\theta \leq \hat{\theta}}{E} u^{f'}[Z^{\alpha}] (Z^{\alpha}_{E}) + \underset{\theta > \hat{\theta}}{E} u^{f'}[Z^{\alpha}+\pi] (Z^{\alpha}_{E}) + f(\hat{\theta}) \frac{d\hat{\theta}}{dE} \{u^{f}[Z^{\alpha}(\hat{\theta})] - u^{f}[Z^{\alpha}(\hat{\theta}) + \pi]\} \tag{C6}$$

where $Z^{\alpha}(\theta) = W(E(P),\theta) - P^{\alpha}(D(E(P),\theta))$ and $\frac{d\hat{\theta}}{dE} = -\frac{D_{E}(E,\hat{\theta})}{D_{\theta}(E,\hat{\theta})} < 0$. Then,

$$\lim_{\hat{\theta} \uparrow \overline{\theta}} U^{f}_{E}[B^{\alpha}(\hat{D},\pi),E(P^{o})] = U^{f}_{E}[P^{\alpha},E(P^{o})] + \lim_{\hat{\theta} \uparrow \overline{\theta}} f(\hat{\theta}) \frac{d\hat{\theta}}{dE} \{u^{f}[Z^{\alpha}(\hat{\theta})] - u^{f}[Z^{\alpha}(\hat{\theta}) + \pi]\} \tag{C7}$$

For $\alpha = 0$, then $P^{\alpha} = P^{o}$ and given a $\bar{\pi} > 0$ we have

$$\lim_{\hat{\theta} \uparrow \bar{\theta}} U_E^f[B^o(\hat{D},\bar{\pi}),E(P^o)] = \lim_{\hat{\theta} \uparrow \bar{\theta}} f(\hat{\theta}) \frac{d\hat{\theta}}{dE} \{u^f[Z(\hat{\theta})] - u^f[Z(\hat{\theta}) + \bar{\pi}]\} > 0 \quad \text{(C8)}$$

$U_E^f[B^{\alpha}(\hat{D},\bar{\pi}),E(P^o)]$ is continuous on the compact set $T(\alpha,\hat{\theta}) = \{(\alpha,\hat{\theta}) | \alpha \in [0,1], \hat{\theta} \in [\underline{\theta},\bar{\theta}]\}$ so that U_E^f is also uniformly continuous on $T(\alpha,\hat{\theta})$. By (Thm 16.12 of Bartle, p. 162) this implies that $\lim_{\hat{\theta} \uparrow \bar{\theta}} U_E^f$ is continuous in α. Thus (C8) implies that there exists an $\alpha' > 0$ such that

$$\lim_{\hat{\theta} \uparrow \bar{\theta}} U_E^f[B^{\alpha}(\hat{D},\bar{\pi}),E(P^o)] > 0 \text{ for } 0 \leq \alpha \leq \alpha' \quad \text{(C9)}$$

In addition, since U_E^f is continuous in $\hat{\theta}$, there exists some θ' sufficiently close to $\bar{\theta}$ such that

$$U_E^f[B^{\alpha}(\hat{D},\bar{\pi}),E(P^o)] > 0, \text{ for } \theta' \leq \hat{\theta} < \bar{\theta} \quad 0 < \alpha \leq \alpha' \quad \text{(C10)}$$

Note that for $\pi = 0$, $U_E^f[B^{\alpha}(\hat{D},\pi),E(P^o)] = U_E^f[P^{\alpha},E(P^o)]$ for all α and $\hat{\theta}$. By Lemma 2, assuming α' is sufficiently small we have,

$$U_E^f[B^{\alpha}(\hat{D},0),E(P^o)] = U_E^f[P^{\alpha},E(P^o)] < 0 \text{ for } \theta' \leq \hat{\theta} < \bar{\theta} \quad 0 < \alpha \leq \alpha' \quad \text{(C11)}$$

Combining (C10) and (C11) we have

$$U_E^f[B^{\alpha}(\hat{D},\bar{\pi}),E(P^o)] > 0 > U_E^f[B^{\alpha}(\hat{D},0),E(P^o)] \quad \text{(C12)}$$

for all $(\alpha,\hat{\theta}) \in S(\alpha',\theta')$. But this implies that there exists a unique $\pi(\alpha,\hat{\theta}) \in (0,\bar{\pi})$ such that the first order condition for the maximization of $U^f[B^\alpha(\hat{D},\pi),E]$ is satisfied with

$$U_E^f[B^\alpha(\hat{D},\pi(\alpha,\hat{\theta})),E(P^o)] = 0, \quad (\alpha,\hat{\theta}) \in S(\alpha',\theta') \tag{C13}$$

since U_E^f is continuously increasing with π. Furthermore $\pi(\alpha,\hat{\theta})$ is continuous in α and $\hat{\theta}$.

(ii) We now need to show that condition (C13) is also sufficient for a maximum of $U^f[B^\alpha,E]$. Let $\bar{E}(B^\alpha(\hat{D},\pi))$ be the set of E that maximizes U^f given the bonus payment schedule $B^\alpha(\hat{D},\pi)$. Given the continuity of B^α, and $\pi(\alpha,\hat{\theta})$ it follows that $U^f[B^\alpha(\hat{D},\pi(\alpha,\hat{\theta})), E]$ is continuous in E, α and $\hat{\theta}$. Therefore $\sup_E U^f[B^\alpha,E]$ is a continuous function of α and $\hat{\theta}$ and $\bar{E}(B^\alpha(\hat{D},\pi(\alpha,\hat{\theta}))$ is an upper semi-continuous mapping of $(\alpha x\hat{\theta})$ into E. For $\alpha = 0$, $\pi(0,\hat{\theta}) = 0$ and $B^o = P^o$ so that $\bar{E}(B^o)$ is single valued and simply equal to $E(P^o)$. Consequently, for a given $\hat{\theta}$ $|E(P^o) - E(B^\alpha)| \to 0$ as $\alpha \to 0$ for $E(B^\alpha) \in \bar{E}(B^\alpha(\hat{D},\pi(\alpha,\hat{\theta}))$ since $\bar{E}(B^\alpha)$ is U.S.C. and $E(P^o)$ is single valued.

Observe that $U_{EE}^f[B^o,E] < 0$ in a neighborhood of $E(P^o)$ since $E(P^o)$ is the unique interior maximizer of $U^f[B^o,E]$. One can verify that $U_{EE}^f[B^\alpha,E]$ is continuous in α. Consequently $U_{EE}^f[B^\alpha,E] < 0$ in some neighborhood T of $E(P^o)$ for all α sufficiently small. Recall that $|E(P^o) - E(B^\alpha)| \to 0$ as $\alpha \to 0$. Choose α sufficiently small such that $\bar{E}(B^\alpha) \in T$. Then $\bar{E}(B^\alpha) = \{E(P^o)\}$.

<u>Lemma 4</u>: Given the schedules P^o and P^α then

(a) For $\lim\limits_{\theta \uparrow \bar{\theta}} f(\theta) > 0$, a feasible contract-effort pair $[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta})),E(P^{o})]$ exists which dominates $[P^{o},E(P^{o})]$.

(b) For $\lim\limits_{\theta \uparrow \bar{\theta}} f(\theta) = 0$ and $f'_{-}(\theta) < 0$, a feasible contract-effort pair $[B^{\alpha}(\hat{D},\pi(\alpha)),E(P^{o})]$ exists which dominates $[P^{o},E(P^{o})]$.

Proof: (a) Lemma 3 implies that $[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta}),E(P^{o})]$ is feasible for all $(\alpha,\hat{\theta}) \in S(\alpha',\theta')$. By construction $U^{f}[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta})),E(P^{o})] > U^{f}[P^{\alpha},E(P^{o})] = U^{f}[P^{o},E(P^{o})]$. It remains for us to show that $V[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta})),E(P^{o})] > V[P^{o},E(P^{o})]$ for some α, $\hat{\theta} \in S(\alpha',\theta')$. Note that Lemma 1 implies $V[P^{\alpha},E(P^{o})] - V[P^{o},E(P^{o})] > 0$ for $\alpha > 0$. Also $V[P^{\alpha},E(P^{o})] - V[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta})),E(P^{o})] = E_{\theta>\hat{\theta}}[-\pi(\alpha,\hat{\theta})]$ which vanishes in the limit as $\hat{\theta}\uparrow\bar{\theta}$. Consequently for each α sufficiently small there exists a $\hat{\theta}$ sufficiently close to $\bar{\theta}$ such that $[B^{\alpha}(\hat{D},\pi(\alpha,\hat{\theta})),E(P^{o})] > [P^{o},E(P^{o})]$.

(b) Lemma 3 implies $[B^{\alpha}(\hat{D},\pi(\alpha)),E(P^{o})]$ is feasible for α sufficiently small. Treating V and $\hat{\theta}$ as functions of α we obtain,

$$\frac{d}{d\alpha} V[B^{o}(\hat{D}(0),\pi(0)),E(P^{o})] =$$

$$\frac{d}{d\alpha}\left\{\int_{\underline{\theta}}^{\hat{\theta}(\alpha)} P^{\alpha}(D)f(\theta)d\theta + \int_{\hat{\theta}(\alpha)}^{\bar{\theta}} [P^{\alpha}(D) - \pi(\alpha)]f(\theta)d\theta\right\}_{\alpha=0} \qquad \text{(C14)}$$

$$= \frac{d}{d\alpha}\left\{\int_{\underline{\theta}}^{\bar{\theta}} P^{\alpha}(D)f(\theta)d\theta\right\}_{\alpha=0} + f(\hat{\theta}(\alpha))\frac{d\hat{\theta}}{d\alpha}[\pi(\alpha)]_{\alpha=0}$$

where $D = D(E(P^{O}),\theta)$. Note that $P^{\alpha} = P^{O}$ for $\alpha = 0$ and that $[P^{O},E(P^{O})]$ is feasible which implies that either $\pi(0) = 0$ or $\hat{\theta}(0) = \bar{\theta}$. Consequently (C14) reduces to

$$\frac{d}{d\alpha} V[B^{O}(\hat{D}(0),\pi(0)),E(P^{O})] = \frac{d}{d\alpha} V[P^{\alpha},E(P^{O})]_{\alpha=0} = F'(\alpha) > 0$$

by Lemma 1. Consequently there exists an $\alpha > 0$ such that $[B^{\alpha}(\hat{D}(\alpha),\pi(\alpha)),E(P^{O})]$ is feasible and it dominates $[P^{O},E(P^{O})]$.

FOOTNOTES

1. To our knowledge, the first discussion of a property rights approach to limit access to the fishery appears in Christy (1973).

2. See Clark (forthcoming) for an interesting demonstration of this point.

3. On this point see the interesting discussions by Sutinen (1973) and Stiglitz (1974).

4. See page III-41 of Operations Manual for the Regional Fishery Management Council (1976).

5. Despite their practical importance, problems pertaining to the management of multiple specie fisheries will not be dealt with here.

6. Throughout the paper, the derivative of a function is denoted by a "prime", and partial derivatives are denoted by subscripts.

7. We assume the reader is familiar with the fundamental theory of decision making under uncertainty.

8. This approach is used by Spence and Zeckhauser (1971) in their analysis of second best insurance contracts.

9. This approach has been suggested by Harris and Raviv (1978a,b) and by Shavell (1978) for dealing with moral hazard problems that occur in insurance.

10. See page 31658 of Implementation of Northern Anchovy Fishery Management Plan.

11. An interesting analysis of the joint cooperative management of transboundary fisheries appears in Munro (1978).

12. Under the Fishery Management plan for the anchovy, seasonal quotas are set based on estimates of the present spawning biomass. See page 31711-31713 of Implementation of Northern Anchovy Fishery Management Plan.

13. See page 31712 of Implementation of Northern Anchovy Fishery Management Plan.

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