Profit Sharing in Renewable Resource Industries: Implications and Optimal Management

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Abstract

In renewable resource industries, labor is commonly paid with a share of the harvested resource rather than with a per unit-of-effort wage. Share cropping in agriculture is one well-known example and entitlement of the crew to a share of the revenue from the sale of the catch is almost universal among commercial fishing fleets. This paper shows that sharing arrangements have substantial implications for the industry’s profits, optimal resource management, and the resource’s ecological state. Effectively, sharing agreements can interact with fluctuations in natural capital to cause inefficient investment levels and skew industry rents toward labor. As a consequence, optimal regulatory policy for such industries must account for the implications of such sharing arrangements. The model demonstrates why management tools like individual transferable quotas in fisheries, have had unexpected ecological benefits in terms of increasing and stabilizing fishery stocks. Finally, the paper provides an illustrative example using the US Pacific albacore fishery.

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1 Introduction

Firms in renewable resource industries typically pay labor exclusively as a percent of profit or revenue rather than with a per unit-of-effort wage. Such share arrangements exist in share cropping agreements, piece-rate logging contracts and catch share payments in fisheries. Standard textbook treatments (Clark 1990, Hartwick and Olewiler 1998 and Perman et. al. 1990) of the optimal management of renewable natural resources assume that revenue accrues unobstructed to the firm, as when labor is paid a fixed wage rate instead of the observed share remuneration structure. However, renewable resource management instruments conceived under the assumption of fixed wage payments instead of share remuneration regimes can lead to inefficient investment levels, forgone economic rents, and potentially sub-optimal harvesting rules. In some cases, the economic inefficiencies related to such suboptimal management directly lead to larger renewable resource stocks.

Firm revenues, or some function of firm profits, are generally split with labor in renewable resource industries, often accounting for labor’s entire income. The form and size of the split varies across resource type, but labor’s share of profit is substantial. In agricultural crop share arrangements in the Midwestern United States, the rule of thumb split between land owners and farmers is 50% of the agricultural yield (Allen and Lueck 1992). The vast majority of US groundfish troll fleets pay crew between 20-40% of the value of the catch less direct operating costs, such as bait and fuel, with vessel owners paying fixed costs.\footnote{Surveys conducted jointly by US National Marine Fisheries Service (NFMS) and the Pacific States Marine Fisheries Commission between 2003 and 2006 show that roughly 98% of of troll fleets and open access groundfish and salmon fisheries off the west coast of the continental US pay the crew a share of revenue less operating costs.}

On the other hand, piece rate timber contracts split revenue between firm owners and workers. In each case, labor receives no fixed wage component in their remuneration and is instead paid exclusively as a function of firm revenue. For the firm, then, the proportion of labor costs to revenues or profits is a large, constant term. By definition, share remuneration arrangements dramatically affect the rate of marginal revenue earned by firms over different levels of resource extraction.

There are two critical differences between renewable resource industries and other industries that makes implementing share contracts non-trivial. First, the size of resource harvest can vary greatly across time as
a function of exogenous ecological conditions. Second, future resource stocks depend on current exploitation levels. A risk neutral firm in a renewable resource industry invests until its expected private marginal benefit of investment is equal to its expected private marginal cost. If there are externalities in the production process, such as the intertemporal effect of current period exploitation on future resource rents, then private costs do not reflect social costs. A resource regulator seeks to maximize the net present value of the resource by accounting for externalities, so that the firm’s private costs equal social costs. However, when the rate of marginal benefit observed by the firm is affected by share remuneration of labor, the social marginal benefit of investment is no longer equal to the private marginal benefit of investment. Despite the resource manager’s efforts, there is no guarantee that socially optimal industry-wide investment levels will be realized in the presence of share remuneration.

Where there is too little investment and forgone economic rents, though, there may be significant ecological gains. In the case of fisheries, too little investment caused by Individual Transferable Quotas (ITQs) management coupled with profit sharing labor remuneration induces larger breeding populations and fishery stocks. The share remuneration system in conjunction with policy instruments derived under the assumption of fixed wage remuneration induces a tradeoff between economic inefficiency and ecological gain which has implications for harvest targets and rules.

The influence of share remuneration contracts on renewable resource industry investment, profits and management has gone largely untouched in the economics literature with the exception of Hannesson (2000 and 2007). Hannesson (2000) shows via simulation that revenue sharing labor remuneration in ITQ managed fisheries may lead to over- or under-investment. This paper extends Hannesson’s model to analyze the effect of the full linear class of profit sharing labor remuneration arrangements observed in practice on industry investment in all renewable resource industries. Analytical results of the model show the precise conditions under which each share system will lead to suboptimal investment in any resource management strategy conceived under the fixed per-unit-effort wage assumption. Hannesson (2007) shows that a quota tax will not solve the investment problem in ITQ fisheries stemming from revenue sharing but that an output tax will. This paper extends Hannesson (2007) in developing normative management accounting for share remuneration of labor for any choice of policy instrument when an optimal management is possible;
the analysis shows that there are instances in which optimal investment is not possible due to the share remuneration structure. This paper provides empirical evidence that the potential size of the investment inefficiency caused by share remuneration of labor is at least 2% in the case of the US Pacific Albacore tuna fishery. Finally, this paper contributes to the renewable resource harvesting literature and finds that benchmark harvesting rules are no longer generally optimal in the presence of capacity constraints induced by share remuneration of labor.

The remainder of this paper proceeds as follows: section two offers a brief literature review of optimal renewable resource management and places previous research concerning share remuneration in context. Section three extends the fisheries model of Hannesson (2000) to incorporate all share contracts observed in renewable resource industries and introduces classical policy instruments designed to maximize economic rents from renewable resource extraction. This section also analytically evaluates the implications of the various share remuneration schemes on a firm’s investment level. Section four simulates investment inefficiencies resulting from naïve management policies. Section five offers normative policy accounting for profit sharing remuneration in renewable resource industries. Section six uses data from the Alaskan halibut and sablefish fisheries to illustrate the influence of remuneration agreements on industry level investment and the ecological benefits that can be associated from share remuneration in ITQ fisheries. This section performs a calibration exercise using data from the US Pacific albacre tuna troll fleet to show the lower-bound for the investment inefficiency caused by naïve management. Section seven examines the intertemporal effects on the resource stock caused by investment inefficiency and shows that previously standard harvest rules might fail as a result. Section eight offers some concluding remarks.

2 Previous Literature

There is one intratemporal externality and one intertemporal externality associated with renewable resources, both of which motivate their management. The intratemporal externality concerns problems arising from ill-defined property rights leading to the commons problem while the intertemporal externality concerns maximizing long run expected resource rents. There is a large literature addressing both externalities asking
which policy instrument is most efficient conditional on the ecological and economic environment as long as wage payments are fixed and exogenous. There is also a smaller unrelated literature which seeks to explain why share remuneration is observed in renewable resource industries. This section summarizes both lines of research in the context of the current paper.

There is considerable anthropogenic pressure on the world’s renewable resources. World fisheries are in decline (Worm, et. al. 2008), deforestation is rampant (Granger et. al. 2002) and soil erosion from agricultural overuse is a concern (Lal 1999). In every case, the anthropogenic effects relate directly to economic market structures which lead individuals to overexploit the resource. Classifying renewable resources as common property is one common market structure which leads to ecological over-exploitation of renewable resources.

In a certain world, it is well understood that externalities leading to the commons problem in renewable resource industries may be efficiently remedied by taxes or the enforcement of property rights (Gordon 1954 and Schlager and Ostrom 1992). Either prices or quantities can be an efficient policy instrument so long as they equate private costs of the firm with social costs to eliminate the dissipation of rents associated with common property. Further, Weitzman (1974), Weitzman (2002) and Hannesson and Kennedy (2005) all examine whether quantities or prices serve as the best regulatory tool in the presence of different types of ecological and economic uncertainty given exogenous wage payments in renewable resource industries. Even in cases where property rights exist in name, lack of enforcement can create de facto common property requiring additional policy instruments for optimal management of fisheries, forestry, agriculture and water (Sjostedt and Taylor 2007). In every case, though, existing literature assumes labor is remunerated as a fixed wage and revenue accrues unobstructed to the firm. If labor is remunerated as a share of profit, then the regulatory problem is misspecified and could lead to inefficient outcomes. Hannesson (2000) is the only research addressing the share remuneration issue in renewable resource management. His work shows that revenue sharing in a fishery with ITQs may lead to suboptimal investment in physical capital.

The intra-period externality which leads to overexploitation of renewable resources is related to the inter-period effect which can cause long run resource stock overexploitation. Complex and idiosyncratic ecological relationships dictate how fast renewable resources grow over time. Disease, cyclical ecological conditions
and technological change all have implications for resource harvest rates (Condeso and Meentemeyer 2007, Carson et. al. 2008 and Murray 2008). The collapse of many fisheries is one clear example of overexploitation of renewable resources, but some forestry and agricultural practices have adversely affected the ecological state of forests and topsoil quality (Worm et. al. 2009, Costello et. al. 2009, Pimental et. al. 1995, Rodrigues, et. al. 2009). Choosing how much of a renewable resource to exploit every period can be a difficult task and complicated interdependent ecosystems can make the problem even more difficult. As such, many nations have developed regulatory bodies that collect all relevant information and oversee the rate at which renewable resources are exploited every year. Even when harvest rates are determined by a regulator, though, policy instruments still may matter. Costello et. al. (2009) shows that ITQ managed fisheries are healthier than those managed solely with catch limits.

The precautionary principle as developed in Arrow and Fisher (1974) is potentially the most well known intertemporal environmental management rule. The precautionary principle states that it is optimal to exploit less of a renewable resource when there is a positive possibility of resource stock collapse. Using a different model, Reed (1979) shows that so long as there are no industry capacity constraints, a regulator should harvest the resource stock down to a level that is a function of ecological parameters, but never past it. Costello and Polasky (2008) and Sethi et. al. (2005) extend Reed’s model to incorporate complicated ecological relationships and find that Reed’s “constant escapement policy” continues to be optimal.

Other intertemporal relationships in renewable resources have been shown to induce managers to combine policy instruments. Pizer (2002) has shown that there may be benefits to using hybrid regulatory policies for climate change in the case of price uncertainty. Smith (2009) shows that high-grading behavior in fisheries, the practice of dumping low value fish for high value fish can be eliminated by using a tax in conjunction with ITQs.² In every case, either economic or ecological uncertainty merits a combination of policy instruments to control for externalities associated with renewable resources.

A small and unrelated literature which examines the motivations for implementing a share remuneration system in renewable resource industries. The existence of share remuneration arrangements has been attributed to both risk-sharing by firm owners and a solution to principal-agent moral hazard problems.² Hannesson 2007 also considers a directly related hybrid regulatory policy that is discussed below.
The risk-sharing explanation for share labor payments is deeply entrenched in the crop sharing literature and has been studied with respect to fisheries as well. Cheung (1969) developed a model further analyzed by Allen and Lueck (1999) showing that in natural resource industries with highly variable output, share remuneration reduces the variability of income to the principal. Plourde and Smith (1989) use a similar argument to explain share contracts in fisheries. Share remuneration in renewable resource industries is also attributed to ameliorating the moral hazard problem of non-contractible effort in a principle-agent setting. This explanation has received considerable attention in the share-cropping, piece-rate forestry and fisheries literatures (Allen and Lueck 1992, Gibbons 1987, McConnell and Price 2006). In each case, this sphere of research examines firm level outcomes such as productivity or optimal share levels.

While the firm level implications of share remuneration have been considered in the literature, little work examines the industry level effects implementing a share remuneration structure in renewable resource economics. Share remuneration in renewable resource industries affect industry level outcomes, and thus merit study, for three reasons. First, incomplete or unenforced property rights in renewable resource industries often leads regulators to use policy instruments such as taxes, property rights, harvest limits and command and control production techniques to maximize long run resource rents and ensure resource stock health. If the regulator does not account explicitly for the remuneration structure to labor in designing their policy instruments, the interaction of these policy instruments amounts to a specification error in the regulator’s problem. Second, there is significant ecological variability due to natural and anthropogenic idiosyncrasies that affect the exploitation of renewable resources. As such, altering the rate of profit flows to firm owners by implementing share labor contracts changes incentives to invest. Third, any within period inefficiencies are magnified in renewable natural resource industries since resource stock levels are intertemporally related.

The implications of paying labor as a share of profits or as a share of revenues on the management
and profitability of renewable resources industries have received little attention in the economics literature. McConnell and Price (2006) show that unaccounted for share remuneration regimes leads to important implications for econometric estimation of fishery production functions. Hannesson (2000 and 2007) is the first and only work to analyze the share remuneration issue as it relates to industry level outcomes and resource management. Hannesson (2000) shows that revenue sharing in a fishery managed by ITQs may lead to suboptimal investment in physical capital. Hannesson (2007) shows that only with an appropriate landings tax will ITQs lead to optimal investment in a revenue sharing fishery. In essence, Hannesson (2000 and 2007) identifies a particular case in which augmenting the flow of revenue to firm owners can change investment decisions and that only some policy instruments can take this into account.

3 A Simple Model of Renewable Resource Industries

Consider a model of renewable resource extraction in which the size of the available resource harvest is subject to some uncertainty. Such is the case in farming where yield is subject to some climate variability, forestry in which case the amount of forest to be harvested or seeded varies with idiosyncratic shocks like disease or weather and a fishery managed with an idiosyncratic total allowable catch (TAC) due to dynamic ecological factors (see Sethi et. al. 2005 Carson et. al. 2008). For the purpose of exposition, we use the example of fisheries managed with TAC limits, which is a typical arrangement in the United States and many other countries. In a TAC managed fishery, the regulator is able to observe the catch of all vessels in the fishery. When the sum of all the vessels catch equals the TAC set by the regulator for that season, the fishery is shut down. TAC managed fisheries are open access, meaning that anyone who registers with the regulatory body overseeing the fishery may enter. As a result, TAC managed fisheries suffer from the

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5 There is a small literature studying how the adoption of ITQ management affects remuneration structure and crew earnings. Casey et. al. (1995) observes that upon implementing ITQ management in the Alaskan Halibut fishery, crew remuneration shares were kept constant in well over half of the vessels and crew shares went up or down in roughly equal proportions on other vessels. Knapp (2006) examines the effect of quotas on employment in the Alaska Crab fishery, but not in the context of remuneration structure. Brandt and Ding (2008) examine the implication of ITQs in the mid-Atlantic surf clam fishery and find no statistically significant effect on pay. Abbott, Barber-Yonts and Wilen (2009) find that remuneration shares stay roughly constant in Alaskan crab fisheries after the implementation of ITQs.
commons problem. The TAC in a given period, \( t \), is assumed to be the realization of a random variable with an associated time invariant pdf \( f(\cdot) \).

Following Hannesson (2000), consider a model in which there are \( N_t \) homogeneous firms in an industry at time \( t \). Each firm has some production capacity \( k \) which is invariant across time. Firms are assumed to have some capital cost \( K \), some depreciation rate \( d \) and subject to some rental rate \( r \). More generally, \( K(r + d) \) can be thought of as the yearly fixed cost of lumpy physical capital units which must be used in the renewable resource extraction process. Note that capital investment is assumed to have a cost every period, irrespective of whether the capital is used in the period. Further, in this model, market participants cannot substitute between capital and labor. Rather, firms choose a vessel size whose productivity is maximized for a given crew size. These assumptions are somewhat restrictive but not entirely unreasonable in renewable resource industries. Casey et. al. (1995), Brandt and Ding (2008) and Abbott et. al. (2009) each find almost no significant changes in per boat crew sizes, or share levels, in fisheries that switch between open access TAC management and ITQ management.

In agriculture, potential crop harvest is dictated by climate and in both forestry and fisheries harvest is usually set by a resource manager respond to ecological variations. In the model, the amount of natural capital available for harvest in a period \( t \) is represented by \( Q_t \). \( Q_t \) is a random variable drawn from a time invariant distribution \( f(\cdot) \) which has bounded support \([Q_{min}, Q_{max}]\). The distribution \( f(\cdot) \) can be thought of as the distribution of a resource stock which incorporates equilibrium ecological and economic variables such that long run industry profits are maximized. As a result of the homogeneity assumption, the resource stock \( Q_t \) is split evenly among firms such that production per firm in year \( t \) is \( \min[k, \frac{Q_t}{N_t}] \) where \( k \) is firm level capacity.

In the model, firms make a one-time entry decision. Since the distribution of natural capital is fixed across time, though, the entry decision is redundant from one period to the next as long as prices, \( p \), are assumed to be constant. For simplicity, assume time invariant operating costs \( c \), and time invariant physical capital factor payments, \((d + r)K\), must be paid by the firm.\(^6\) In the baseline case, assume that labor is paid.

\(^6\)All the analysis in this section go through if unit costs are decreasing in resource stock size. In some cases the results are magnified. In any case, constant unit costs are assumed so as to highlight the nature of the inefficiencies which can result from
with a standard fixed wage rate, \( w \). Given these assumptions, the expected profit in the fishery described above is given by

\[
EV = (p - c) \left[ \int_{Q_{min}}^{kN} Qf(Q)d(Q) + kN(1 - F(kN)) \right] - (d + r)KN - wN
\]  

(1)

Using the example of a TAC managed fishery, the first term with the brackets represents the average industry catch when the TAC is below fleet capacity \( kN \) and the second term represents the proportion of the time the TAC exceeds the fleet’s harvest capacity. The total industry wage bill, \( wN \), will take different forms depending on which remuneration regimes, either parametric wages, scale wages or profit sharing- is modeled. This will become clear as different remuneration regimes are introduced below.

### 3.1 Different Share Remuneration Regimes

The different remuneration regimes to be analyzed are introduced in this section. All share regimes are assumed to be linear in either revenue, operating profits or total profits.\(^7\)

**Scale Wages**

Hannesson (2000) considers a special case of renewable resource property rights management, the ITQ managed fishery. In the Hannesson model, the right to harvest quota is evenly allocated across a fleet, and firms pay labor as a share of total revenue. This is precisely the piece-rate structure common in forestry. In this remuneration regime, capital owners earn a share of the gross revenue, \( x \in (0,1) \), leaving labor a share of size \( 1 - x \). In this case, an individual firm owner has expected revenue of

\[
EV = (px - c) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1 - F(kN)) \right] - (d + r)K. 
\]  

(2)

\(^7\)Non-linear share structures, such as a fixed wage rate with bonus pay tied to resource harvest are briefly considered in the simulation section below but are generally beyond the scope of this paper.
Note in equation 2 that the wage term has been replaced by the share of gross profit which accrues to the firm owner.\(^8\) As a result, labor’s total expected remuneration, \(E[M|x]\) for a given season equals

\[
E[M|x] = p(1 - x) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1 - F(kN)) \right] > w. \tag{3}
\]

It is important to recognize that in any remuneration regimes, labor’s expected remuneration must be at least as large as their opportunity wage, \(w\). Note that it could be the case that equation 3 could constrain and determine the industry’s production capacity, \(kN\).\(^9\) Further, while economic theory derived in McConnell and Price (2006) suggests that firms choose a remuneration structure and share sizes to maximize their own profits in fisheries, the NFMS and PSMFC surveys mentioned above show a large amount of variation in remuneration regimes both within and across fisheries.\(^10\) To simplify the exposition here we will take the firm’s share, \(x\), as given and not the result of a richer dynamic optimization problem.

*Operating/Full Profit Sharing*

Now consider an operating profit sharing labor remuneration regime common in most OECD fisheries. 98% of west coast troll fisheries and many sharecropping agreements in developing countries remunerate labor by share revenue less direct operating costs. In such regimes, the crew is usually paid as a share of the operating profit (e.g., the profit excluding capital rental costs). In this case, the expected revenue accruing to the firm owner would be

\[
EV = x(p - c) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1 - F(kN)) \right] - (d + r)K. \tag{4}
\]

\(^8\)For notational ease, for the remainder of the paper, it shall be assumed the \(kN \leq Q_{max}\).

\(^9\)Indeed, labor’s participation constraint may be why this subject received little attention in the past: there is no counter-factual where labor does not participate in a renewable resource industry, by definition.

\(^10\)There are at least two explanations for this finding. First, there could be substantial heterogeneity with respect to vessel/crew ability or information sets. This could lead to different values of \(x\) being optimal for different owners. Second, individual vessel owners may behave sub-optimally by conforming to industry norms and fail to adjust this parameter. In support of this second claim, Casey et. al. (1995) shows that over half of halibut fishing vessels did not change remuneration regimes in response to the transition from open access to ITQ management. Abbott et al. (2009) finds the same stability in Alaskan crab fisheries.
Here, $x$ is the share of profit which accrues to the firm owner. In this case, labor’s expected share of the profit simply equals

$$E[M|x] = (1-x)(p-c) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1-F(kN)) \right] \geq w. \quad (5)$$

In the case of full profit sharing, a firm maximizing expected profits will take into account that capital rental costs are being shared with labor.\textsuperscript{11} Full profit sharing was found to be present in many artisanal fishing communities studied by McClanahan and Mangi (2001).\textsuperscript{12}

**Profit Sharing with Feedbacks**

It is possible that as the share of the profit to be received by labor increases, labor will work harder to increase the profit margin per unit of production in order to increase their own pay. This feedback effect explored by McConnell and Price (2006) could confound the yield per unit effort if effort is endogenously determined with the scale wage. Since effort decisions are not made without considering the profit share, fee management could become more difficult to optimally implement since setting an optimal fee becomes increasingly complicated.

Consider a profit sharing remuneration regime where the percent of operating profit which accrues to the crew, $(1-x)$, endogenously affects labor’s effort and in turn the firm’s unit costs. For the exposition that follows we consider a fishery although the same model can clearly be applied to forestry or agriculture.

In the fishery, the expected revenue accruing to the vessel owner under profit sharing with feedback effects is

$$EV = x \left[ (p-c(e)) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1-F(kN)) \right] \right] - (d+r)K. \quad (6)$$

\textsuperscript{11}Formally, this amounts to $EV = x(p-c) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1-F(kN)) - (d+r)K \right].$

\textsuperscript{12}Note that full profit sharing results in the maximum amount of risk sharing for firm owners. As such it is not surprising that we observe this remuneration structure in highly variable stocks.
Here, $c(e)$ is a strictly convex function representing the marginal per unit cost of fishing, with $e$ representing crew effort. The accompanying expected crew remuneration in this model is

$$E[M|\lambda] = (1-x) \left[p - c(e) + \int_{Q_{min}}^{kn} \frac{Q}{N} f(Q) d(Q) + k(1-F(kN)) \right] \geq w.$$ (7)

In this model, costs are not parametric but rather a function of effort, $e$ which will be endogenously chosen by the crew. The precise form of the crew’s maximization problem is elaborated upon in appendix A. As a result, the remuneration parameter '$x$' could have a feedback effect on the productivity of the fishing vessel. In this extension, crew member productivity will be inversely related to the operating cost of the vessel in equilibrium. Thus, time at sea, fuel use and time to the processor might all be reduced if remuneration rates are increased in a model with scale wage feedbacks.\(^{13}\) Note that the crew’s share $(1-x)$ is multiplying total operating profits.

### 3.2 Different Management Regimes

Renewable resource management is needed most in the absence of well-defined property rights. In open access fisheries and agricultural production in less developed countries, economic rents can be dissipated due to poor enforcement of property rights. In the absence of establishing enforceable property rights, taxes or fees may be used as a policy instrument to affect entry and investment into the industry. This subsection introduces three policies- property rights, taxes on price and taxes on capital- which may lead to optimal renewable resource management. Given that firms are homogeneous in this model, resource rents are maximized for a given industry size, $N$. Therefore, optimal renewable resource management is defined as management that induces the optimal industry size. To this end, the absence of any management and optimal management are introduced as benchmark cases. This section introduces property rights, output taxes and capital taxes derived under a fixed wage assumption and derives analytical results for the influence of such policy instruments on resource rents and labor outcomes.

\(^{13}\)Time to the processor might actually affect price, but a more general notion of profit per unit of fish subsidies this issue. Therefore, nothing is lost by assuming all benefits accrue through cost.
It is well known that open access to a renewable resource leads to a full dissipation of economic rents. Under open access entry an investment will occur until the expected economic profit of entry is zero. Thus, setting the expected value of the resource, represented by equations 1, 2, 4 and 6, equal to zero will implicitly define the equilibrium number of firms in open access under the four different share remuneration regimes.

**Optimal Management**

In this model, the social planner maximizes the expected annual profit of the renewable resource with respect to the number of firms in the industry. The reason why the capacity issue is relevant is that there is annual variation in the natural resource stock available for exploitation but yearly fixed costs of capital. As such, over-investment implies that the industry is paying too much in yearly capital costs relative to the natural resource stock’s distribution. The canonical example of over-investment is fleet capacity in a fishery. Treating the number of firms as a continuous variable, the maximization problem for the social planner amounts to maximizing expected revenue, equation 1, with respect to $N$. As shown in Hannesson (2000), Liebnitz’s rule yields the first order condition

$$(p - c)k(1 - F(kN)) = (d + r)K + w.$$  

(8)

This equation shows that the expected marginal revenue of an additional firm must equal the marginal social cost of adding another firm in equilibrium under optimal management. Note that in both the case of profit sharing or exogenous wage payments, it need not be the case that total production capacity equals the maximum amount of natural capital to be exploited. Given that physical capital payments must be made in each period, if the chance of a very large exploitable natural capital stock is small, it may not be efficient from the social planners perspective to invest in additional capacity that may only rarely be used. Put more precisely, if the percentage of time the fleet capacity will be exceeded is small, $(1 - F(kN))$, then the frequency with which the marginal firm will be needed to reach the available resource stock will be small.

**Property Rights**

Establishing enforceable property rights is perhaps the most attractive method of regulating a renewable natural resource. In the case of the timber industry, different sections of forest are auctioned off to be
harvested by logging companies. Upon winning a contract, the company has exclusive use rights over the resource in that area. A similar arrangement arises with share-cropping in the developed world. This section uses ITQ managed fisheries as a concrete example of property rights management.

Equilibrium in the ITQ system is defined as the point at which the owner of one ITQ gains the same revenue from either selling the ITQ or fishing. Assume that a quota is evenly distributed across the fleet such that each boat receives $\frac{1}{N}$ of the TAC $Q_t$ set by the regulator. If an owner of quota size $\frac{1}{N}$ wishes to cease fishing and sell her quota to the remaining boat owners, she maximizes sale revenue when she sells equal quota shares to all vessel owners who remain in the fishery. Therefore, the sum of each vessel owner’s willingness to pay for additional quota is the sum of each firm’s expected increase in profits if one vessel exits and its quota is evenly split among remaining vessels. Equilibrium is reaches when the value from quota sale is equal to the value of continue fishing.

ITQ regimes are well understood when crews are paid a parametric wage and lead to efficient outcomes. However, Hannesson (2000) shows that ITQ management with a revenue sharing may lead to excessive or insufficient fleet capacity. Taking the case of operating profit sharing, the sum of the industry’s willingness to pay for additional quota is given by:

\[-N \frac{\partial ER}{\partial N} = x(p - c) \int_{Q_{min}}^{\min[kN, Q_{max}]} \frac{Q}{N} f(Q) d(Q). \quad (9)\]

Intuitively, the willingness to pay for additional quota of the vessel owners who stay in the fishery is equal to the increase in expected profit they gain by purchasing the quota. Boat owners gain from purchasing additional ITQ only when their catch share is less than vessel capacity, $Q_t/N < k$.

For a given share level, $x$, in ITQ management equilibrium the the expected revenue from selling quota to existing vessels must be equal to the expected revenue from continued fishing. This condition is represented by setting equation 9 equal to equation 4, which after some algebraic manipulation yields

\[x(p - c)k(1 - F(kN)) = (d + r)K. \quad (10)\]

Equation 10 implicitly defines industry size, $N$, as a function of the firm’s share, $x$, and other parameters. Therefore, given the motonicity of $F(\cdot)$, $N$ is increasing $x$ in equilibrium as long as labor’s participation
constraint is satisfied. Intuitively, as the share accruing to the firm rises, the economic value of continued harvesting rises faster than the revenue from selling the property right because purchasing additional quota is only worthwhile when a firm harvest is below firm capacity, $Q_t/N < k$, due to the homogeneity assumption. As a result, additional firms enter by buying the right to harvest up to the point where the operating profit earned by capital owners equals the price which they could earn by selling the property right and exiting the industry.

Taxes on Output

An ideal tax regime lowers the resource price to the point where the expected economic profit of adding capital is zero at the social planner’s optimum production capacity.

In order to calculate an optimal tax, the regulator must increase the cost of additional production capacity such that firms earn zero expected economic profit at the rent maximizing production capacity. Again, using fisheries management as an example, assume that TAC varies randomly according to $f(Q)$. As a result, the social planner must choose a percent of tax on the price to be paid at landing of $\tau$ such that the expected profit of an additional boat is zero if $N$ is at its optimal level as defined by equation 1, $N^*$:

$$
((1 - \tau)p - c) \left[ \int_{Q_{\text{min}}}^{kN^*} \frac{Q}{N^*} f(Q)d(Q) + k(1 - F(kN^*)) \right] - (d + r)K - w = 0.
$$

(11)

Implicitly defines $\tau$ as a function of the parameters of the particular fishery where $N^*$ is the fleet capacity which comes from maximizing industry profits with respect to $N$ (e.g., the social planner’s choice of $N$).

Firm Licensing Fee/Tax on Capital

Enforceable property rights are not plausible in many remote fisheries and marginal agricultural land in the developing world. Where property rights enforcement is costly, price instrument can be an effective management tool. An ideal firm licensing fee or capital tax management regime in the model would raise the per period cost of capital to the point where the expected economic profit of an entering firm is zero at the social planner’s production capacity. If $\Phi$ is taken to be the licensing fee, then the optimal fee is implicitly
defined by the equation

\[(p - c) \left[ \int_{Q_{min}}^{kN^*} \frac{Q}{N^*} f(Q)d(Q) + k(1 - F(kN^*)) \right] - (d + r + \Phi)K - w = 0 \tag{12} \]

3.3 Analysis

Regulatory policy constructed under the assumption of fixed wage payments in renewable resource industries using share remuneration will often lead to inefficient levels of investment in the industry. This subsection presents analytical results for different combinations of remuneration regimes and naively designed regulation. The inefficiencies associated with property rights management are presented first, followed by taxes on output and capital.

First consider equilibrium under property rights management in an industry using operating profit share remuneration, such as with many ITQ managed fisheries. Equilibrium industry capacity, given fixed wage, remuneration is implicitly defined by equation (8) under property rights management and by equation (10) if labor is remunerated by operating profit sharing. Rearranging terms, the following set of equations show equilibrium industry capacity in each case, with \(N^*\) representing optimal industry size under fixed wage remuneration and \(N_{OP}\) representing equilibrium industry size under operating profit sharing remuneration:

\[(p - c)k(1 - F(kN^*)) = (d + r)K + w \tag{13} \]

\[x(p - c)k(1 - F(kN_{OP})) = (d + r)K \tag{14} \]

These two equations immediately lead to the following proposition.

**Proposition 1:**

*If labor earns at least their opportunity wage and the cdf of resource harvest is strictly monotonic, operating profit sharing remuneration in conjunction with property rights management leads to an efficient industry size only if the share that accrues to firms equals the capital cost’s share of total costs.*

**Proof.** Equation (13) is the property rights equilibrium condition with fixed wage payments and equation (14) is the property rights equilibrium condition under operating profit remuneration with \(N_{OP}\) the
according equilibrium fleet capacity. Since the cdf, $F(\cdot)$ is assumed to be strictly monotonic, there is a unique industry capacity which satisfies equation 13. Impose $N_{OP} = N^*$ and divide equation (14) by equation (13). The condition under which sharing operating profit property rights management will give the optimal fleet capacity:

$$\frac{(r + d)K}{(r + d)K + w} = x$$

(15)

This expression gives the desired result. ■

For any set of parameters, then, there exists a unique share level, $x$, which leads to optimal industry size. However, there is no reason why the share that accrues to capital owners must equal the unique share level which guarantees optimality in general. If the share accruing to a harvest-right owner is less than the capital cost share, it means that the value of fishing for the capital owner is too little relative to their capital contribution to the production process and investment is too low relative to the optimum. On the other hand, as the marginal value of harvesting increases via quota owners’ share increasing, firms stay in the industry until there is over-investment.

Thus far, we have assumed that labor’s remuneration constraint does not bind in the analysis. However, for a given share level, $x$, optimal industry might not be attainable without violating labor’s participation constraint. In order to determine the effect of a binding remuneration constraint on investment, again compare the equilibrium condition in operating profit sharing with property rights management, equation (14), and the equilibrium condition under optimal management, equation (8). Property rights management coupled with operating profit remuneration optimal investment when the remuneration level when each vessel is operating at capacity is equal to the opportunity wage of labor:

$$(p - c)(1 - x)k(1 - F(kN)) = w.$$  

(16)

The proper interpretation of equation (16) is that the wage $w$ given in the labor market must be equal to labor’s remuneration when the fleet is fishing at full capacity. However, the harvest level in any period, $Q_t$, is the realization of a random variable. If the share wage paid to the labor, $(1 - x)$, was determined by the
labor market, such that expected crew remuneration was equal to the opportunity wage, the 
would be defined in the equation

\[(p - c)(1 - x) \left[ \int_{Q_{min}}^{\min[kN, Q_{max}]} Q f(Q) d(Q) + k(1 - F(\min[kN, Q_{max}])) \right] = w. \tag{17}\]

However, as long as \(\int_{Q_{min}}^{\min[kN, Q_{max}]} Q f(Q) d(Q) > 0\), it must be the case that the wage condition in equation (16) is less than the expected wage share given in equation (17). Thus, as the probability of resource harvests below a given level of industry harvest capacity increases, the larger the difference between the expected share remuneration and the opportunity wage. Put another way, as the likelihood of realizing harvests below the industry capacity increases, the distortion caused by share remuneration increases. As such, increased variation in the renewable natural resource will lead to increasing distortion if labor is remunerated as a share of operating profit. Hannesson (2000 and 2007) finds a similar result in the case of revenue sharing in ITQ managed fisheries.

If the expected remuneration of labor is less than or greater than the opportunity wage, then the labor market is in disequilibrium. This can be examined analytically in the operating profit sharing model. The result of the analysis is the following proposition.

Proposition 2:

In an operating profit sharing regime under property rights management, labor’s expected remuneration is always above their opportunity wage at optimal fleet capacity as long as the resource harvest size varies and is dictated by a continuous and strictly monotonic cdf.

A full proof is in the Appendix but the intuition is as follows: labor is paid a share of operating profits at every level of production and not just at the maximum production capacity or at the investment margin. At the optimal industry size the firm’s expected operating profit is less than the amount there would have been had labor been remunerated with a fixed wage because firms share profits even when the realized harvest is low. This creates a rent transfer to those laborers who stay in the industry but leaves those who exit earning

\[14\]If the crew is risk loving or risk averse, expected remuneration will be less than or more than the opportunity wage, respectively.
the opportunity wage determined by the broader labor market. The only way that there can be an efficient level of investment is if labor earns resource rents.

Next consider the case of full profit sharing in a property right management structure where firms share capital costs with labor. Such is the case in many artisanal fisheries. As with operating profit sharing, equilibrium industry capacity is implicitly defined when the expected profit from continued operation is equal to the income earned by selling the harvest-right. This condition is satisfied when

\[
x(p - c) \int_{Q_{\min}}^{\min[kN,Q_{\max}]} \frac{Q}{N} f(Q)d(Q) = x(p - c) \left[ \int_{Q_{\min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1 - F(kN)) - (d + r)K \right]. \tag{18}
\]

This equilibrium condition will always lead to overinvestment relative to the social planner’s optimum if labor’s remuneration constraint does not bind.

**Proposition 3:**

In a full profit sharing regime under property rights management, as long as the cdf of resource stock harvest is strictly monotonic, there will always be overinvestment in the industry so long as the labor’s remuneration constraint does not bind. If the remuneration constraint binds, there is a unique point which leads to optimal investment.

**Proof:** Equation (18) can be rearranged such that

\[
\left(1 - \frac{(d + r)K}{(p - c)k}\right) = F(k\tilde{N}). \tag{19}
\]

Comparing equation (19) to the same rearrangement of the social planner’s equilibrium condition with a fixed wage:

\[
\left(1 - \frac{w + (d + r)K}{(p - c)k}\right) = F(kN^*) < \left(1 - \frac{(d + r)K}{(p - c)k}\right) = F(k\tilde{N}). \tag{20}
\]

As long as the opportunity wage is non-zero and the cdf of the resource stock harvest is monotonic, then \(N^* < \tilde{N}\). If the level industry investment is dictated by the remuneration constraint, then investment is
dictated by

\[ E[M|x] = (1 - x) \left[ (p - c) \left[ \int_{Q_{min}}^{k\tilde{N}} \frac{Q}{N} f(Q)d(Q) + k(1 - F'(k\tilde{N})) \right] - (d + r)K \right] = w. \quad (21) \]

Assume that \( N^* = \tilde{N} \). Given this equilibrium condition and using the optimal investment equilibrium condition, optimal investment is achieved when

\[ \int_{Q_{min}}^{kN^*} \frac{Q}{N^*} f(Q)d(Q) + k(1 - F(kN^*)) = w\frac{x}{(1 - x)}. \quad (22) \]

Since the function \( \frac{x}{(1 - x)} \) is monotonic and maps from \([0, 1) \Rightarrow \mathbb{R}^+\), there is a unique \( x \) which solves equation (22).

Intuitively, the reason why there may be overinvestment in the absence of a binding remuneration constraint is that the firm is able to share capital costs with labor. When the capital owners’ share is sufficiently high so that labor’s remuneration constraint is not satisfied, firms must exit until labor’s share meets their reservation wage. Therefore, investment is driven down until it passes through the social planner’s optimum investment level. At share levels below the unique amount which may lead to optimal investment there is underinvestment and at share levels above this amount, there is overinvestment.

Property rights management in conjunction with revenue sharing remuneration has the same rent sharing implications as operating profit sharing remuneration developed in proposition 2.\(^{15}\) The share level under which revenue sharing arrangement leads to optimal fleet capacity is given by

\[ \frac{p - c}{px - c} = 1 + \frac{w}{(d + r)K}. \quad (23) \]

This expression shows the inverse relationship between labor’s reservation wage and the share level which gives optimal fleet capacity. As the reservation wage moves toward zero, the revenue which must accrue to the capital owner in order to ensure optimal investment approaches one. As in the previous cases, if the remuneration constraint binds, then equilibrium investment is determined by labor’s expected remuneration being equivalent to the reservation wage, and optimal fleet capacity may not be realized.

\(^{15}\)This is the remuneration and management pairing examined by Hannesson (2000) using simulation techniques, although Hannesson 2000 focused specifically on ITQ managed fisheries.
Now consider using price instruments constructed under the assumption of fixed wage payments to alleviate the dissipation of rents caused by the lack of enforceable property rights. If labor is remunerated with fixed wage payments, price instruments can be more desirable than quantity instruments in the case of significant ecological uncertainty or if costs of property rights enforcement is high (Weitzman 2002). In constructing optimal taxes, a regulator changes the prices observed by firms in order to induce optimal investment but all rents are transferred to the regulatory body.

Take the case of a tax on output where $\tau$ is the tax level set by the regulator assuming fixed wage labor payments is implicitly defined by equation (11). If such a tax rate, $\tau$, was constructed assuming fixed wage labor payments and used in an operating profit sharing remuneration regime, then the resulting equilibrium investment would be optimal if and only if the share is equal to the share of total costs from capital as in equation (15), the same condition which would lead to optimal fleet capacity in a property rights management regime. This result is not surprising; optimal taxes align private costs with social costs in precisely the same way as internalizing social costs via property rights management. As before, though, there is no guarantee that this be true in general, in which case investment is too great or too little.

Alternatively, an operating profit sharing remuneration structure in conjunction with a fee on capital constructed under a fixed wage assumption as in (12) will never lead to optimal industry capacity unless labor receives no share ($x = 1$).\[^{16}\] If labor earns no share then there will always be overinvestment if a renewable resource is regulated with naively constructed taxes on capital if labor is remunerated as a share of operating profit. However, if labor earns no share then the remuneration constraint clearly binds. When the remuneration constraint binds, there is a unique level for which investment is optimal and maximum resource rents are captured by the regulator. The proof of this result is similar to that in proposition 3 and is not included here.

The combination of revenue sharing arrangements and price instruments leads to similar conclusions as those of operating profit share arrangements and price instruments. In fact, a tax on output constructed under the fixed wage assumption will lead to optimal investment in the presence of revenue sharing arrange-

\[^{16}\]The result follows after letting equation (12) implicitly define the fee $\Phi$ and solving for the operating profit share, $x$, which gives optimal investment.
ments if capital owners’ share is equal to the share or total costs from capital as is equation (15). This is the same condition which would lead to optimal fleet capacity in a property rights management regime and a tax on output in the presence of operating profit sharing. Revenue sharing in conjunction with a capital fee will never lead to optimal industry capacity unless labor receives no share \((x = 1)\) as with an output tax. In the case of output taxes, optimal investment occurs if capital owners earn the proportion of income that is due to their contribution to the production process because labor shares the relative change in the output price. In the case of capital fees, labor does not share the cost of the increased capital costs but the benefits from increased investment continue to accrue to them. The reason for the similarities between revenue sharing and operating profit sharing is that in both cases labor does not split capital costs. When labor shares the cost of capital with capital owners, as in full profit sharing remuneration regimes, similarities quickly break down.

The combination of full profit sharing remuneration agreements and price instruments (either taxes on output or capital) lead to the most stark investment inefficiencies. As stated above, optimal taxes change prices so that at the optimal industry size, the expected profit of an entering firm is zero. If labor is paid with a fixed wage, taxes will not affect the income of labor that stays in the industry. If labor shares revenues less operating costs and capital costs, though, a price instrument would imply that labor earns no income at the optimal fleet capacity.

Consider the firm’s incentives with a tax derived under the fixed wage assumption in equation (11):

\[
x((1 - \tau)p - c) \left[ \int_{Q_{min}}^{kN*} \frac{Q}{N^{tau}} f(Q)d(Q) + k(1 - F(kN*)) \right] - (d + r)K = 0
\]  

Equation 24 can be interpreted to mean that firms enter until there is no expected profit from doing so under the new price structure. Setting \(N^{tau} = N^*\) implies that share level \(x\) which gives optimal fleet capacity is \(x = 0\). A share level of \(x = 0\) implies that capital owners earn no income. As a result, there is a multiplicity of equilibria: firms earn no income for any level of investment. Therefore, if \(x = 0\), labor’s remuneration constraint determines investment levels and the remuneration constraint binds at optimal fleet capacity. If \(x > 0\) then the remuneration constraint determines the investment level and capacity is always
below the optimal level.\textsuperscript{17} The same intuition applies for fees on capital derived under the assumption of fixed wage payments in equation (12). As a result, we conclude that price instruments constructed under a fixed wage assumption will always lead to the remuneration constraint being binding and lead to underinvestment in all non-trivial cases.

Table 1 shows the findings in this section. Generally, any linear share economy applied to renewable resources scale wage pay regimes can lead to over- or under-investment in a property right management regime. If price instruments are used, then full profit sharing will inevitably lead to underinvestment, but other share remuneration structures can lead to over- or under-investment. It must be the case that if labor is remunerated via operating profit sharing then they must earn some fraction of resource rents at the optimal industry investment level.

### Table 1: Industry Capacity Relative to Optimum

<table>
<thead>
<tr>
<th>Remuneration Regime</th>
<th>Management Regime</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Property Rights</td>
</tr>
<tr>
<td>Scale Wage</td>
<td>Over/Under</td>
</tr>
<tr>
<td>Full Profit Share</td>
<td>Over/Under</td>
</tr>
</tbody>
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#### 3.4 Variable Unit Profits

Profit per unit of output in renewable resource harvests is usually thought to vary with the size of the renewable resource stock. Intuitively, if the resource stock is very large, then the cost of harvesting a given amount of the resource might be relatively smaller than if the resource stock size was very small. The Hannesson (2000) model extended here assumes that unit of output profits are constant across all harvest

\textsuperscript{17}Intuitively, labor must earn 100\% of income in a full profit sharing scheme under price instrument regulation because price instruments rotate the industry’s marginal benefit or marginal cost curves. However, share remuneration also rotates the industry’s marginal benefit curve. When labor earns all income, these two effects offset each other leading to optimal fleet capacity.
sizes. If the target harvest size chosen by the resource regulator is indicative of the stock size, as almost always the case in well managed renewable resource industries, then it is important to understand how relaxing the constant unit profit assumption affects investment dynamics addressed in this paper.

The most developed model in renewable resource economics in which profits are responsive to resource stock size is in fisheries. In fisheries, the classical Gordon-Schaefer model specifies that total fishing profits are
\[
\pi(X) = PqEX^\alpha - cE
\]
where \(P\) is price, \(q\) is the catchability coefficient, a measure of overall efficiency, \(E\) is a metric for fishing effort, \(X\) is the stock size of the target species and \(\alpha\) is the stock elasticity, which indicates how sensitive costs are to the size of the target species. For a given level of fishing effort and stock size, a species with a larger \(\alpha\) produces higher unit profits than if \(\alpha\) is low within the permissable range, \(\alpha \in [0, 1]\). The Gordon-Schaefer model embeds the constant unit profit model when \(\alpha = 0\).

In the Gordon-Schaefer model, profit per unit effort is \(\frac{\pi(X)}{E} = PqX^\alpha - c\). The first and second derivative of unit profits are
\[
\frac{\partial \pi(X)}{\partial X} = \alpha PqX^{\alpha-1}
\]
\[
\frac{\partial^2 \pi(X)}{\partial X^2} = (\alpha - 1)\alpha PqX^{\alpha-2}.
\]

By inspection, the first derivative of unit profits is positive and the second derivative is negative. The function \(\alpha(1 - \alpha)\) is zero if \(\alpha = 1\) or \(\alpha = 0\) and is largest in magnitude when \(\alpha = .5\).

Now consider a generalization of the Hannesson (2000) model in which unit profits are a function of stock size and there is a monotonic function mapping stock size \(X\) to realized TAC \(Q\). Without loss of generality, unit profits can be written as \(\pi(Q)\) where \(\pi'(Q) > 0\) and \(\pi''(Q) < 0\), as implied by the Gordon-Schaefer model. The following two equations show the augmented total expected value from resource harvest in the model with variable unit profit under exogenous wage payments and operating profit sharing:

\[
EV = \int_{Q_{min}}^{kN} \pi(Q)N \frac{Q}{N} f(Q) d(Q) + kN(1 - F(kN))\pi(kN) - (d + r)KN - wN \quad (25)
\]
\[
EV = x \int_{Q_{min}}^{kN} \pi(Q)N \frac{Q}{N} f(Q) d(Q) + kN(1 - F(kN))\pi(kN) - (d + r)KN \quad (26)
\]

As before, the equations differ only by the exclusion of the exogenous wage in equation and inclusion of owner share level \(x\) in equation (26). A social planner maximizes expected rents by maximizing equations
\[
\begin{align*}
\left(\pi'(kN^*)+\pi'(kN^*)\right)k(1 - F(kN^*)) &= (d + r)K + w \quad (27) \\
x\left(\pi(kN^*)+\pi'(kN^*)\right)k(1 - F(kN^*)) &= (d + r)K \quad (28)
\end{align*}
\]

In both first order conditions, the constant unit profits are embedded in the more general case. As before, the proper interpretation of the equilibrium conditions is that the marginal benefit of adding another vessel must be equal to the marginal cost. The difference between the FOCs in equations (27) and (28) and the FOCs with constant unit profits is the inclusion of an additional term which embodies the change in unit profits when harvesting at industry capacity as industry capacity increases, \(\pi'(kN^*)kN^*\). If there is a significant increase in unit profits when stock sizes are large, then there is an additional benefit to adding capacity because the additional capacity can recover more of the relatively higher rents.\(^{18}\)

As in the constant unit profit model, in order for profit sharing to give the socially optimal level of investment observed in the exogenous wage payments case, expected crew remuneration at when the industry is harvesting at capacity must equal the opportunity wage of the crew:

\[
(1 - x)[\pi(kN^*) + \pi'(kN^*)kN^*]k(1 - F(kN^*)) = w. \quad (29)
\]

As in the case of constant unit profits, optimality implies that the crew earns resource rents at optimum capacity. Further, deviations from this share level lead to suboptimal investment levels.

The more general model of unit profits implies that deviations from the share level \(x^*\) leading to optimal industry capacity can cause either greater or smaller deviations from optimal fleet capacity relative to the constant unit profit case. To see this, consider the equilibrium condition in operating profit remuneration, equation (28). Dividing both sides by the share level which leads to optimal capacity, \(x^*\), gives

\[
\pi(kN^*) + \pi'(kN^*)kN^*k(1 - F(kN^*)) = \frac{(d + r)K}{x^*}. \quad (30)
\]

\(^{18}\)One problem of the modeling approach is that if unit profits vary with stock size, unit profits increase for all resource stocks corresponding with a harvest limit larger than capacity. Put another way, \(\pi(kN)\) is not constant \((1 - F(kN))\) percent of the time. This doesn’t affect comparing the unit of effort wage remuneration with share remuneration within the model, though.
Now consider a deviation away from $x^*$ to $\bar{x} < x^*$. There exists a suboptimal industry size $N$ implied by $\bar{x}$. By taking the derivative of the left hand side of equation (30) with respect to $N$, we can compare how the more general specification affects the size of any potential investment inefficiency.

The derivative of the left hand side of equation (30) can be written as

$$-k^2 f(kN)\pi(kN) + k^2 [(1 - F(kN))(2\pi'(kN) - kN\pi''(kN)) - f(kN)kN\pi'(kN)].$$

(31)

First note that the term outside the bracket on the left corresponds to the constant unit profits case and is negative. Negativity of this term implies that as the share retained by owners falls relative to its optimum ($x$ goes down) and the right hand side of (30) increases, investment levels $N$ must fall. This is precisely what is shown in Proposition 1 and in the simulations.

The contents of the bracketed term is contributed by the more general specification of variable unit of effort profits. If the term is zero, then there is no difference in the rate of investment inefficiency caused by deviations from the share level leading to optimal capacity between the extended Hannesson (2000) model and the model presented here. When the content of the bracketed term is negative it means that a given fall in $N$ leads to a more dramatic increase in the left hand side term in equation (30). In this case, the investment inefficiency is less severe than it would be in the case of constant unit profits. When the content of the bracketed term is positive, it means that a given fall in $N$ leads to a less dramatic increase in the left hand side term in equation (30) and the investment inefficiency is more severe.

The key to determining the sign of the contents of the bracket term in (31) is the middle component $-kN\pi''(kN))$. As shown above, the Gordon-Schaefer model implies $\pi''(kN) < 0$. Further, if the stock elasticity is near the center of the permissable range, $\alpha = .5$, then the magnitude of the term is large and if the stock elasticity is near the bounds of the permissable range, $\alpha = \{0, 1\}$, then the magnitude of the term is small. As such, we would expect the inefficiencies caused by share remuneration to be largest for species with stock elasticities in the middle of the permissable range as the middle term in (31) becomes larger.

Note that nothing in the model prevents the entire term (31) from being positive. If the term were positive, when levels that are too low would lead to overcapacity, which is the opposite implication of the extended Hannesson (2000). The expression in (31) will be positive if changes in unit profits at stock levels
associated with large catch limits are larger than levels of unit profits at those same stock levels. While this is a possibility in the model, it is highly unlikely in practice.

4 Simulations

This section shows how share remuneration can affect investment in renewable resource industries for all management regime introduced in the previous section. The simulations show the size of the economic inefficiencies caused by share remuneration has a particular set of parameters.

In the simulations below, we follow Hannesson (2000) in assuming the following functional forms:

- \( Q \sim U[Q_{\text{min}}, Q_{\text{max}}] \)
- \( Q_{\text{min}} = 0 \) and \( Q_{\text{max}} = 100 \)
- \( p = 1, d = .1, r = .05, w = .25, K = 1 \) and \( k = 1 \)

Given these functional forms and parameter values the remuneration models presented above will be analyzed with respect to the different natural resource management regimes. Excluding the efficiency wage remuneration model, there are nine possible permutations of remuneration and management strategy in addition to the social planner’s solution where labor is paid their opportunity cost, \( w \).

While this simulation is applicable for investment in agricultural development, production capacity in forestry or investment in fisheries, consider for concreteness the example of fleet capacity in a fishery. The problem of over-capacity in fishing fleets is well documented in open-access fisheries. This section shows how any linear share economy can affect fleet capacity in the different management regimes presented in the previous section. In this case, total production capacity, \( kN \), can be thought of as fleet capacity \( N \).

Figures 1, 2 and 3 show the results from simulating fleet capacity and expected crew remuneration on three different remuneration regimes and three regulatory regimes designed when assuming fixed wage payments. In each case, the figures also show the optimal equilibrium fleet capacity reached in the case of parametric wage structure as a baseline. Each combination of share remuneration and regulatory regime
Figure 1: Capacity Under Property Rights Management with Operating Profit Sharing Remuneration as a Function of Percent $x$ Paid to Owner

was selected to show a general characteristic that is present in each of the nine combinations simulated. Full results for all 9 combinations are shown in Table 1 above.

Figure 1 combines ITQ management with operating profit sharing. This is the share remuneration and regulatory structure in place in the halibut and sablefish fisheries in Alaska. Moving from left to right on the $x$ axis, a larger share of operating profits accrues to the owner. In this case, potential vessel owners are constrained by paying the crew their opportunity cost of labor. As such, for each incremental increase in the share of operating profits accruing to the vessel owner, the fleet size increases as long as the remuneration constraint does not bind. The reason for the increasing production capacity is that while that marginal cost of adding another boat is fixed at the rental cost of capital, the marginal benefit of adding another vessel is changing. The level of operating profits accruing to the quota owner rises as their share rises. As a result, as owners’ share increases, more vessels will enter the fishery until the marginal vessel drives per vessel profits back to the marginal cost of investment. This result is true so long as the remuneration constraint doesn’t bind.

The discontinuity in figure 1 occurs due to the labor’s participation constraint binding. When the expected remuneration constraint binds, labor’s expected remuneration requirement dictates the level of
investment as opposed to the management regime. Because we consider only linear share remuneration, this model does not allow firms to offer a fixed wage component to offset the incompatibility property right dictated equilibrium and labor force participation. Over the region where fleet capacity discretely jumps in Figure 1 due to the remuneration constraint being binding, a non-linear profit sharing agreement could be reached that guarantees labor their opportunity wage in expectation. In this case, though, capital owners would in effect be sharing a percentage of their resource rents it with labor to make the remuneration guarantee, thus moving back to, effectively, a higher labor share.\textsuperscript{19}

Clearly, there are significant inefficiencies in natural resource management that result from the share economy in the case where the labor input payments bind. The reason for the significance of the jump is that the crew’s executed remuneration doesn’t account for the physical capital payments yet it fully accounts for the remuneration which occurs over the entire range possible TACs $[Q_{\text{min}}, Q_{\text{max}}]$. Also, as the owners’ share increases beyond the level after which the remuneration constraint binds, production capacity begins to fall to compensate labor for decreased percentage share with increased per vessel revenue.

Finally, Figure 1 shows that the fleet capacity may be either below or above the optimal level. Over-investment would occur if firms’ share is greater than the capital cost share, $x > \frac{(d+r)k}{(d+r)k+w}$, and labor’s participation constraint holds, $E[M|x] \geq x$. Since labor earns resource rents at optimal fleet capacity, there is always a range over which these conditions are met. Labor earning rents at optimal industry capacity due to the share structure drives this result.

Figure 2 shows the inefficiencies associated with setting a naive tax on capital in the presence of scale wages.\textsuperscript{20} With respect to fisheries, a capital tax may be thought of as a yearly licensing fee on fishing vessels. A naive regulator constructs the capital tax by assuming fixed wage payments and choosing the tax so as to set industry economic profits equal to zero at the optimal fleet capacity. Scale wages are unique in that the remuneration structure doesn’t have the crew directly sharing any of the regulatory costs with the vessel owner. This implies that the fleet size increases with the share accruing to the vessel owner as fishing becomes more individually profitable until the point where the vessel owner is constrained by the crew’s

\textsuperscript{19}To the author’ knowledge, non-linear labor remuneration agreements are much less common than fully linear share agreements.

\textsuperscript{20}Note that scale wages with ITQ management replicates the simulations in Hannesson (2000)
remuneration constraint. When the expected remuneration falls below the opportunity wage of the crew, vessels begin to exit (as with the case above) in order to drive up individual vessels revenues to be shared with labor.

Figure 3 shows perhaps the most theoretically interesting combination of regulatory regime and remuneration regime: full profit sharing and output taxes. With respect to fisheries, a tax on output can be implemented as a landings tax. An optimal tax is derived by assuming an exogenous wage and setting expected industry profits to zero at the optimal fleet capacity by taxing the price received by firms for their output. Under full profit sharing, though, the vessel owner receives a certain percentage of the total profit. Further, the crew must receive at least their opportunity wage. Therefore, if any of a vessel’s total profit accrues to the vessel owner under a landings tax regime (or a tax on capital regulatory regime) the crew will receive less than their opportunity wage. The result is that a landings tax will leave the owner with zero economic profit which is exactly what the original goal of the policy was. Thus, a landings tax in a full profit sharing regime where the vessel owner earns a positive portion of the profit will inevitably lead to below optimal fleet capacity. A landings tax will reduce fleet capacity over what it had been under open access. A similar result holds for licensing fees and full profit sharing. The implications for full profit sharing in
Figure 3: Capacity Under Output Tax Management with Full Profit Sharing Remuneration as a Function of Percent x Paid to Owner

renewable resource industries are that price instruments of any kind lead to under-investment.

We now show simulation results for an operating profit sharing remuneration structure when there are effort feedbacks effects. Two different functions relating cost and effort are assumed and integrated in the model presented above:

1. \( c(e) = 1 - \frac{e^{1-\gamma}}{1-\gamma} \)
2. \( c(e) = \exp(-\gamma e) \)
3. \( g(e) = e \)
4. \( f(Q) = \frac{1}{Q_{max} - Q_{min}} \)
5. \( F(Q) = \frac{Q - Q_{min}}{Q_{max} - Q_{min}} \)
6. \( Q_{min} = 0 \) and \( Q_{max} = 100 \)

These functional forms were chosen to show the sensitivity of the simulation results to the relative curvature of the cost function. Cost specification 1 has decreasing absolute curvature as defined by Arrow-Pratt, \( \gamma/e \), and specification 2 has constant absolute curvature, \( \gamma \). The implication is that in specification 1,
costs are less sensitive to effort at high levels than low levels. Simulations were performed so as to evaluate different levels of the operating profit share $x$ and different measures of cost function curvature. Figure 4 shows how fleet size varies with both $x$ and $\gamma$ in the model of scale wages with feedback effects with cost specification 1. Figure 5 shows the same graph using cost specification 2.

Figure 4 shows that for a given $\gamma$, a measure of responsiveness of cost with respect to effort, the number of boats in the fleet is essentially constant across different crew shares. Whereas excluding effort feedbacks implies fleet capacity is increasing in the owners’ revenue share when the remuneration constraint doesn’t bind, including effort feedbacks that may imply that fleet capacity is not increasing in owners’ revenue share on this region. The reason is the decision by the crew to trade off between income and effort. The implication is that if the crew’s expected remuneration is low, they will shirk and reduce the potential profit to be received by the quota owner because the unit costs of fishing are now relatively higher. Further, additional boats will decrease the average share of profits for each pre-existing crew. This externality imposed on the remuneration of all crews by newly introduced vessels reduces the incentive to invest since additional vessels will decrease effort and increase unit costs via lower expected remuneration for all levels of effort.

Figure 5 shows that while feedbacks can potentially temper the distortion caused by profit sharing in
Figure 5: Investment under operating profit remuneration and ITQ management with feedback effects under cost function 2. Plane is set at 50, the fleet size under optimal management.

renewable resource production processes, it can also exacerbate them. If the cost function exhibits constant relative curvature, then the resulting inefficiency from the share economy in renewable resources could be made worse. It is important to note that it makes drawing industry-specific conclusions about profit sharing an empirical question.

It is apparent in these figures that fleet size is increasing in the elasticity of cost with respect to effort. This makes intuitive sense since the marginal benefit of effort to workers is greater when effort is increased. As such, lower unit costs lead to increased value of resource extraction. In sum, over- or under-capacity is tempered by effort feedbacks if the cost function exhibits decreasing relative curvature and is potentially exacerbated if the cost function exhibits constant relative curvature.

In a property rights management with fixed wage payments, as the wage rate falls, investment will rise. We find the opposite result here: if labor is to be paid a low profit share, then there is less of an incentive to invest since little effort is expended and unit costs are high. When the labor is paid a higher share, there is more effort, increased industry profits, and as a result, more investment.
5 Optimal Management Accounting for Remuneration Regime

It is possible to account for realistic remuneration regimes in fishery management and reach a first best solution. Take, for example, the case of ITQs and operating profit sharing. Operating profit sharing is by far the most common remuneration regime in fisheries. As stated above 98% of the Pacific coast troll fleet use some form of operating profit sharing. An ITQ regime will lead to too much or too little fleet capacity due to a vessel owner not receiving the full benefit from holding an ITQ, as they must share some of the resource rents with the crew. One way to ensure optimal investment levels is to use a hybrid regulatory policy which incorporates both tax and quantity regulation. Pizer (2002) has shown that there may be benefits to using hybrid regulatory policies for climate change in the case of price uncertainty. Smith (2009) shows that high grading behavior in fisheries can be eliminated by using a tax in conjunction with ITQs. Hannesson (2007) shows that inefficient fleet capacity caused by revenue sharing in ITQ managed fisheries cannot be remedied with taxes on quota holdings but may be remedied by appropriate pairings of taxes and revenue sharing levels. The results here are different from Hannesson (2007) in that they are robust to all pairings of regulatory regime and share structures and account for labor’s remuneration constraint. The results presented here show that using taxes on output or capital in conjunction with property rights renewable resource management can lead to first best investment level.

We have seen that operating profit remuneration with property rights management can lead to over- or under-capacity in renewable resource industries. The equilibrium for property right management is given by setting the cost of adding another capital unit to the expected marginal revenue accruing to an owner of providing the investment. Under operating profit sharing, equilibrium is defined by

\[ x(p - c)k(1 - F(kN)) = (d + r)K. \]  (32)

This will by no means lead to the optimal investment levels. If it does then labor must earn a share of the economic rents as shown above.

Consider an alternative management structure that combines a vessel licensing fee (or subsidy) with property rights management. Assume the regulator derives the first best level of investment \( N^* \) assuming
Figure 6: Optimal capital tax under ITQ management with operating profit sharing as a function of share $x$ paid to vessel owner.

that labor earns its opportunity wage. All that is left is to solve for the capital tax $\Phi$ which gives the optimal $N^*$ as the equilibrium to the augmented property rights regime, ensuring that labor is paid at least the opportunity wage in expectation. This amounts to implicitly solving the following equation for a capital tax: $\Phi(N^*)$:

$$x(p-c)k(1-F(kN^*)) = (d + r + \Phi(N^*))K$$  \quad (33)

$$s.t. \ (1-x)(p-c)\left[\int_{Q_{min}}^{kN^*} \frac{Q}{N^*} f(Q)d(Q) + k(1-F(kN^*)) \right] - (d + r + \Phi(N^*)) \geq w$$  \quad (34)

In order to show how the optimal capital tax varies over different share levels, consider again the example of ITQ management in fisheries. In this simulation, an optimal capital tax is constructed in conjunction with ITQ management and operating profit sharing remuneration so that fleet capacity $N$ is at the social planners level. Assume the same parameters as before.

Figure 6 shows the schedule of optimal capital taxes for different levels of owner’s profit share in the same simulated fishery used above. In this simulation, while capacity is not constrained by crew remuneration requirements, the fleet should be subsidized at some fixed amount per vessel in order to ensure optimal
fleet capacity. The degree of the subsidy or tax on vessels or landings will be subject to the traits of a particular fishery as shown in the calibrated model below. Note that once the owner’s share exceeds 45% in this particular simulation, the optimal fee is zero. The reason for this result is that at this point, the expected remuneration condition binds determining fleet capacity and ITQ management no longer dictates capacity unless a non-linear class of remuneration structures are considered.

Constructing optimal output or capital taxes accounting for realistic remuneration regimes is relatively simple in the absence of property rights management. Hannesson (2007) shows that in a fishery, a tax on landings can lead to optimal fleet capacity if the crew is paid as a share of total revenue, but that a tax on quota holdings would serve no purpose other than to transfer rents from industry to regulator and this result be can replicated here. The optimal tax or fee is found in a similar way as in the ITQ case above, but the equilibrium condition is slightly different since a price instrument is used as opposed to an ITQ which regulates quantity:

\[
E[V] = x((1 - \tilde{\tau})(p - c) \left[ \int_{Q_{min}}^{kN^*} \frac{Q}{N^*} f(Q) d(Q) + k(1 - F(kN^*)) \right] - (d + r + \tilde{\Phi}))K = 0 \quad (35)
\]

\[
s.t. \ E[M;x, \tilde{\tau}, \tilde{\Phi}] \geq w \quad (36)
\]

This expression suppresses the precise remuneration regime. It may be noted that as long as the remuneration regime is accounted for explicitly, then it is possible to find a first best policy instrument via either a tax on output \(\tilde{\tau}\) or capital \(\tilde{\Phi}\).\(^{21}\) This amounts to the regulator correctly specifying their objective function.

6 Empirical Example and Calibration Exercise

In this section, empirical evidence for the implications of the theoretical model is given using data from the Alaskan halibut and sablefish fishery. The theoretical model is then calibrated using data from the North Pacific albacore tuna fishery and an optimal policy is developed based on the calibrated parameters. In both cases, the predictions of the theoretical model appear to be present and significant.

\(^{21}\)It is worth noting that taxes on quota holdings can be effective in either operating or full profit sharing remuneration regimes.
Before 1995, both the sablefish and halibut fisheries in Alaska were managed by industry level total allowable catch limits (TACs). Any licensed vessel could enter and fish until the sum of all vessels’ catch reached the fishery’s catch limit.\textsuperscript{22} From 1960-1994, the value of the annual sablefish and halibut catch ranged from roughly $100-250 million and from 1979-1994 the fleet exceeded catch limits by an average of roughly 5\% (CGER 1999).

In 1995, the regulatory body overseeing the two fisheries implemented tradeable property rights over both the Alaskan halibut and sablefish longline fisheries. Due to congruent season times, fishing gear and fishing techniques, all owners of halibut quota also own sablefish quota. Operating profit sharing was the remuneration scheme before and after the ITQ management implementation (Casey et. al. 1995). In this fishery, quota shares are transferable but the total amount of landings associated with a quota share fluctuates in direct proportion to the quota share as in this paper’s theoretical model.

The model presented here implies that operating profit sharing in a property rights management regime such as ITQs in fisheries can lead to either over- or under-capacity of the fishing fleet relative to the social planner’s optimum. If this particular fishery suffered from over-investment then regardless of TAC, we might expect the entire TAC to be caught in every period. Alternatively, if the fishery were under-capitalized, we would expect to observe less than 100\% of the TAC taken in on average and that in high TAC years we observe excessively low takes.

Data was collected for TAC levels and landings levels for both sablefish and halibut from 1991-2009 by NFMS. The data from 1991-1994 is included to show the dramatic over-harvesting that occurred during that time period. Data from the 1980s was not included, as there was significant fishing pressure from other nations such as Taiwan and Russia during that time period. Summary statistics are presented in Table 2, organized by years.

It is immediate from the data that under-capacity might be an issue in this fishery.\textsuperscript{23} The halibut fishery

\textsuperscript{22}At the end of the season, it was common during this time for the regulator to place effort controls on the fishery to avoid passing the TAC.

\textsuperscript{23}Redstone (2007) found that ITQ managed fisheries generally don’t catch the entire TAC in a given year but are agnostic as to why.
Table 2: Summary Statistics for Alaskan Halibut and Sablefish Fisheries by Season: 1991-2009

<table>
<thead>
<tr>
<th>Species</th>
<th>Data Type</th>
<th>1995-2009 Average</th>
<th>St. Dev.</th>
<th>pre-1995 average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sablefish</td>
<td>TAC Weight (tons)</td>
<td>32,600</td>
<td>4948</td>
<td>47,200</td>
</tr>
<tr>
<td></td>
<td>Catch Weight (tons)</td>
<td>29,700</td>
<td>4264</td>
<td>47,400</td>
</tr>
<tr>
<td></td>
<td>Catch/TAC</td>
<td>.912</td>
<td>.02</td>
<td>1</td>
</tr>
<tr>
<td>Halibut</td>
<td>TAC Weight (tons)</td>
<td>52,000</td>
<td>7500</td>
<td>47,100</td>
</tr>
<tr>
<td></td>
<td>Catch Weight (tons)</td>
<td>50,100</td>
<td>7,920</td>
<td>48,400</td>
</tr>
<tr>
<td></td>
<td>Catch/TAC</td>
<td>.96</td>
<td>.03</td>
<td>1.03</td>
</tr>
</tbody>
</table>

NOTE: Data from National Marine Fisheries Service Alaska Regional Office

was larger over this time frame and fishermen earned a price premium on halibut.\footnote{Matulich and Clark (2003) found a 35\% price premium on halibut in 1999-2000. Over this time period, the whole sale price of sablefish was $3.01/pound versus $4.15/pound for halibut.} As such, it is reasonable to see that the percent take of the TAC is significantly lower for sablefish than for halibut, as fishermen substitute effort toward sablefish only when marginally profitable to do so.

If under-capacity is an issue in this fishery, the econometrician would observe that in years where the TAC for halibut is high, the percent of TAC for sablefish taken would be low, given the price premium earned by fishermen on halibut. Table 3 presents the results of three regression specifications that test whether this is observed in the data. In each specification, the dummy variables are used to control for data before the adoption of property rights management in 1995 and the first year after implementing ITQ management was controlled for to account for the transition to a new management regime. In every specification, these controls are highly significant and not reported. The coefficient estimates that are reported are only those on post-ITQ management explanatory variables.

In specification 1 the dependent variable is the sum of sablefish and halibut catches in a given year divided by the sum of TAC for sablefish and halibut allocated in a given year. The explanatory variable in specification 1 is the sum of TAC for sablefish and halibut in a given year divided by the maximum sum of TAC for sablefish and halibut over all years. As the total TAC in the fishery approaches its maximum, if
the fleet is capacity constrained, then the percent of the TAC taken should fall since both species are taken by the fleet. The coefficient on the explanatory variable has the predicted sign but it is not significant. Note that since the data is summed by year in specification one, there are only 16 degrees of freedom in this regression.

In specifications 2 and 3 the data are disaggregated by species. Each specification has the following reduced form, with specification three including the additional bracketed explanatory variable.

\[
\frac{catch_{it}}{TAC_{it}} = \alpha + D'\beta + \frac{TAC_{halibut,t}}{\max(TAC_{halibut})}\beta_1 + \left[1(i = sablefish) \cdot \frac{TAC_{halibut,t}}{\max(TAC_{halibut})}\beta_2 \right] + \epsilon_{it}. \tag{37}
\]

In both specifications, the vector \(D\) represents various controls for the adoption of a new management regime. In specification two, the coefficient on the percent of the maximum halibut TAC is the coefficient of interest. If a fleet suffers capacity constraints then we would expect that as the TAC of the primary species is large relative to other years, then the realized catch is small as a percentage of that TAC. Specification three includes the interaction term for sablefish and the ratio of the current period TAC for halibut to the maximum TAC for halibut.

Neither variable of interest in specification 1 or 2 are significant, but the statistical significance of the coefficient on the added explanatory variable in specification 3 is instructive. The interpretation of the coefficient’s value, -.137, is that if the halibut fishery is allocated its maximum TAC, then the model predicts that the sablefish fishery will catch 1.37% less of their TAC allocated in that season than they would have if the halibut fishery was allocated 90% of their maximum TAC. Put another way, each 10% that the halibut TAC increases, the sablefish fishery catches 1.37% less of their allotment. Further, by adding this additional regressor, we see the intuitive result that the halibut catch significantly increases (at the 10% level) when the TAC for halibut increases. This result implies that fishermen target halibut over sablefish and that this fishery is indeed capacity constrained. These constraints lead to forgone economic rents, however, they also might lead to a larger resource stock.

Given that there is evidence of capacity constraints in a property rights managed fishery, the regulator needs to know the size of the inefficiency to develop a corrective policy. This section calibrates the model presented above using data from the albacore troll fishery off the west coast of the United States. This
Table 3: Regression Results for TAC and Catch in Alaskan Halibut and Sablefish Fishery

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)  (2)  (3)</td>
</tr>
<tr>
<td>year one</td>
<td>-.063***  -.06**  -.059***</td>
</tr>
<tr>
<td></td>
<td>(.002)  (.029)  (.019)</td>
</tr>
<tr>
<td>% max total TAC</td>
<td>-.024  -  -</td>
</tr>
<tr>
<td></td>
<td>(.048)  -  -</td>
</tr>
<tr>
<td>% max Halibut TAC</td>
<td>-  -.008  .06*</td>
</tr>
<tr>
<td></td>
<td>-  (.033)  (.031)</td>
</tr>
<tr>
<td>Sablefish x % max Halibut TAC</td>
<td>-  -  -.137***</td>
</tr>
<tr>
<td></td>
<td>-  -  (.054)</td>
</tr>
<tr>
<td>intercept</td>
<td>.967**  .969***  .911***</td>
</tr>
<tr>
<td></td>
<td>(.041)  (.03)  (.028)</td>
</tr>
<tr>
<td>$r^2$</td>
<td>.56  .60  .65</td>
</tr>
<tr>
<td>$n$</td>
<td>19  38  38</td>
</tr>
</tbody>
</table>

This data was taken from the Alaska Regional Fisheries office of the NOAA.

*** = significant at 1%, ** = significant at 5%, 1 = significant at 10%.

Robust standard errors are used.
fishery remunerates labor as a share of operating profit. Currently, the troll fishery is open access but they are considering adopting ITQ management in order to increase rents. If the albacore fishery were to adopt ITQs as a management regime, then we would expect the number of vessels participating in the fishery to fall dramatically. This exercise uses data compiled from a variety of sources to calibrate the model. The goal of the calibration is to show the magnitude of the difference between the optimal fleet size which would result in the fixed wage case versus the expected fleet size under the observed operating profit share remuneration.

Pacific albacore was chosen because the species has a relatively stable biomass, which gives a lower bound to the magnitude of the investment effect of the share economy in renewable natural resources.

The catch and biomass data are those used for the international resource stock assessments of North Pacific albacore and range from 1981 to 2006 (McDaniel, Crone, and Dorval 2006). Over this time period there was no formal limited entry agreement and this fishery can be thought of as open access. Vessel level panel data on costs is taken from surveys collected by the albacore industry from 1996-1999 (Squires et. al. 2003). Costs are divided into 2 groups: fixed costs and variable costs. Variable costs include both labor costs and other variable costs such as fuel and bait costs. According to the survey cost data, the crew’s remuneration regime in this fishery is operating profit sharing. Fixed costs to vessels are paid by boat owners and variable costs like fuel and bait are shared with the crew.

A Leontief production function is assumed such that the crew’s share of the variable cost is constant over time. This assumption could be called into question if relative prices lead to change in investment rates but for this simple calibration that concern is ignored. Further, there was some variation at the vessel level for the precise crew share, but that information is not available in the data set.

Table 5 shows summary statistics for costs in the US North Pacific Albacore fishery from 1996-1999. The crew’s remuneration accounted for an average of 43.6% of the variable costs in this fishery between 1996 and 1999. Using Baa bond ratings for capital costs from Moody’s as in Squires and Vestergaard (2009), variable costs account for, on average, 45.6% of total costs. A major simplification made here is that vessels are assumed to be uniform. For the calibration, we take 180 short tons to be the capacity of an individual vessel.  

Note that operating profit in Table 3 is calculated before the crew’s share is removed.

---

25 This level is assumed in order to match the days at sea data taken from Squires et. al. (2003). Anecdotal evidence from the American Albacore Fishing Association suggest that a large modern albacore vessel could have a capacity of nearly 300 short
Table 4: Cost Data from US South Pacific Albacore Troll Fishery, 1996-1999

<table>
<thead>
<tr>
<th>Data Level</th>
<th>Category</th>
<th>Ave Cost per Vessel (per ton)</th>
<th>St. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet Level</td>
<td>Number Vessels</td>
<td>866</td>
<td>214.8</td>
</tr>
<tr>
<td></td>
<td>Days per Vessel</td>
<td>39</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Catch per Vessel* (tons)</td>
<td>59.5</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td>Price Albacore (2001 USD/ton)</td>
<td>1,717.56</td>
<td>410.8</td>
</tr>
<tr>
<td>Vessel Level</td>
<td>Crew Remunereration</td>
<td>19,035 (194.40)</td>
<td>11,567</td>
</tr>
<tr>
<td>2001 USD/vessel (per ton)</td>
<td>Other Variable Costs</td>
<td>24,608.97 (413.60)</td>
<td>14,460</td>
</tr>
<tr>
<td></td>
<td>Fixed Costs</td>
<td>52,008 (874.08)</td>
<td>4,613</td>
</tr>
<tr>
<td></td>
<td>Total Costs</td>
<td>95,651.97 (1,607.60)</td>
<td>22,093</td>
</tr>
<tr>
<td></td>
<td>Total Revenue</td>
<td>102,194.82 (1717.56)</td>
<td>56,123</td>
</tr>
<tr>
<td></td>
<td>Operating Profit</td>
<td>77,585.85 (1303.96)</td>
<td>22,935</td>
</tr>
<tr>
<td>Ecological</td>
<td>Biomass</td>
<td>211,130</td>
<td>16,378</td>
</tr>
<tr>
<td>Metric Tons</td>
<td>Yield</td>
<td>13,915</td>
<td>2,829</td>
</tr>
<tr>
<td></td>
<td>Ave. Yield/Biomass</td>
<td>.066</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: Data taken from Squires et. al. (2003), McDaniel et. al. (2006) and Squires and Vestergaard (2009)
Table 5 shows that the average vessel earned just positive accounting profits between 1996 and 1999 although the average vessel. This result is not unexpected given that this fishery was open access over this period. 27.8% of operating profit accrued to the crew.\textsuperscript{26}

Stock assessments from McDaniel, Crone, and Dorval (2006) were fit to a normal distribution with a Shapiro-Wilk test for normality failing to reject the normality assumption. Parameters for potential US TAC allocations were taken from the highly migratory species fisheries management plan as ratified by the National Marine Fisheries Service in 2007 in order to give accurate values for ITQ management. Under the 2007 management plan, the US regional fishery takes roughly 16% of the TAC. The model is calibrated such that the Pacific albacore fishery continues to be sustainably harvested with the TAC taken to be the function of biomass estimates taken from the distribution described by the data.

Unit costs are primarily a function of fuel, damage to product, and bait. The component in variable unit costs associated with diesel fuel is conservatively parameterized at 60\%. This price of diesel fuel was updated to reflect the average price from June 2008 to June 2009, normalized to 2001 US dollars. As such, we use unit costs of $810 per ton rather than the $414 per ton in the original survey data, although both specifications yield similar results. The model was then used to find the expected fleet size relative to the optimal fleet size. Optimal fleet size is derived by assuming that the wage rate observed in the data is the opportunity wage.

Figure 7 shows how fleet capacity in an operating profit regime varies relative to parametric wages over different levels of both owner’s share and variation of the fish stock. Variation in stock is shown as the coefficient of variation ($\frac{\sigma}{\mu}$) of the distribution of the resource stock. The point highlighted on the graph shows the amount of under-capacity, almost 1.3\%, that we would expect to see in this fishery due to the tons. One explanation for the low catch per vessel is not only competition due to open access but fisherman not exclusively targeting Albacore throughout the fishing season. Note that using a percentage difference from optimal fleet capacity can abstract from this parameter.\textsuperscript{26}

It is important to note that fleet capacity for this fishery is not fixed over the time period in which the data were collected since tuna trollers can also be used in other fisheries in seasons that overlap with the albacore tuna fishery. Therefore we calibrate the model using cost and harvest data only for trollers that exclusively fished albacore over this period. This accounts for over 73\% of the observed albacore catch. A different specification using all available data was also performed and yield even more pronounced results.
particular level of the coefficient of variation ($\frac{\sigma}{\mu} = .21$) and operating profit owner’s share ($x = .72$) observed in the data. Proposition 1 implies that a share level of .732 would give first best fleet size. The figure shows that the size of the inefficiency is increasing with the amount of variation due to the share remuneration structure. As such, in renewable resource industries with more variable resource stocks, the size of the inefficiency would clearly be larger given these price levels. The reason that under-capacity is observed in this fishery is due to the price levels observed in the data. Given a different set of prices, ITQ management in this fishery could lead to over-investment. In order to address this under-capacity, the regulator could subsidize fishing activity. A yearly subsidy of roughly $1681 per boat would be needed in the US south pacific albacore fishery to ensure first best investment levels due to the share remuneration structure.

Perhaps more interesting than the investment inefficiency in calibration is the level of remuneration the crew can expect from the share economy in conjunction with ITQ management. The calibration predicts that the crew earns almost twice their previous wage after ITQs are in place so long as the level of share structure does not change. The implications for the political economy of stake-holders in renewable resource industries is clear. In the case of fisheries, although the total quantity of labor employed in the fishery will fall if an ITQ management system is implemented, those who stay in the fishery are predicted to earn more than their opportunity wage.

Figure 7: The Share Economy and US West Coast Albacore Calibration
7 Capacity Constraints and Renewable Resource Management

Profit sharing remuneration agreements between resource owners and labor in natural resource industries have been shown to lead to sub-optimal levels of investment in physical capital. Using an empirical example and a calibration exercise, the ITQ managed fisheries with profit sharing remuneration agreements are undercapitalized relative to the social planner’s optimum. As a consequence, they also appear to be sub-optimally constrained in their harvesting practices. While the economic inefficiency that results from the share economy in renewable natural resource industries is undesirable from a resource rent perspective, constrained natural resource exploitation rates can result in ecological benefits of larger resource stock size and a more resilient resource stock.

To look at this issue, consider a stylized version of the Reed (1979) and Costello and Polasky (2008) models where the stock size of the renewable natural resource is \( x_t \). In the model, the growth function is subject to an idiosyncratic multiplicative shock which creates a stochastic resource stock size. Between periods, the resource stock grows according to a concave surplus growth function \( f(\cdot) \), and a multiplicative error term \( z_t \), subject to a cumulative distribution function \( \Phi(z) \) with mean one and support \([0, b]\) where \( b \) is finite:

\[
x_{t+1} = z_t f(e_t) \quad \text{s.t. } e_t = x_t - h_t.
\]

(38)

Here, \( e_t \) can be thought of as escapement and \( h_t \) the level of harvest in period \( t \).

In the model, price is assumed to be some time invariant \( p \) and a unit cost function \( c(x_t) \) is assumed to be decreasing and convex in \( x_t \). Given this cost structure, there will be a stock level, defined as \( \hat{x}_t \), for which within period marginal profits are driven to zero, or \( p = c(\hat{x}_t) \). Define the level of stock size left by the myopic harvester who maximizes current period profits only as \( \underline{x} = \max(0, \hat{x}_t) \). We can then define the
within period profit of harvesting from a starting stock size $x$ down to $x$ as

$$Q(x) = p(x - x) - \int_x^x c(s)ds. \quad (39)$$

Given a constant discount factor, $\delta$, we can write the stochastic dynamic programming summarizing the social planner’s problem of maximizing resource rents as

$$V_t(x_t) = \max_{e_t} [Q(x_t) - Q(e_t)] + \delta E[V_{t+1}(x_{t+1})]. \quad (40)$$

Within this framework, Costello and Polasky (2008) shows equation (40) is a “state independent control problem” meaning that the optimal control is invariant to the value of the current state variable. Intuitively, this implies that the current stock size does not affect the level of stock the social planner wishes to allow be left to rebuild at the end of the harvest period. As such, optimal management is characterized by allowing some level of constant escapement, $S$, which maximizes expected rents.

A simple extension of the model is developed here in order to find the stock dynamic created underinvestment, and capacity constraints in general, in renewable resource industries. Consider the same problem with the added constraint that industry capacity might not allow for full resource harvesting. If the industry harvesting capacity is represented by $\overline{h}$, the constraint is

$$\text{if } x_t - \overline{h} < 0, \ e_t \in [0, x_t] \ \text{else } e_t \in [0, x_t - \overline{h}]\label{const}$$

First consider how adding a capacity constraint like equation (??) affects a naive regulator who does not account for capacity constraint and continues with a constant escapement policy. Assume that the constant escapement level set by this regulator is $e^*$ and that $f(e^*) - e^* < \overline{h} < bf(e^*) - e^*$. Not accounting for capacity constraints leads to a larger expected stock size in all future periods.

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Reed (1979) and Costello and Polasky (2008) do not consider the share remuneration structure. Wages and capital costs are subsumed into the unit cost function. As such, the within period profit function in the share economy may be written as

$$\tilde{Q}(x) = \kappa[p(x - x) - \int_x^x c(s)ds]$$

where $\kappa$ is less than one. If $\kappa$ is constant over time, then including it in this particular modeling approach is trivial. As such, this term is left out in this section’s exposition.
Proposition 4. Non-trivial renewable natural resource harvesting constraints lead to a larger expected stock size in future periods if not accounted for.

Proof. Rewrite the dynamic programming problem in equation 3 as

$$V_t(x_t) = \max_{e_t} [Q(x_t) - Q(e_t)] + \delta E_t [Q(x_{t+1}) - Q(e_{t+1})] + \delta^2 E_t [V_{t+2}(x_{t+2})]. \quad (42)$$

Assuming the continued use of the harvesting rule without capacity constraints, escapement is defined as

$$e_{t+1} = \begin{cases} e^* & \text{if } e^* \geq x_{t+1} - \overline{h} \\ x_{t+1} - \overline{h} & \text{if } e^* < x_{t+1} - \overline{h} \end{cases} \quad (43)$$

Note that escapement in period $t+1$ will be greater than 'naive' optimal escapement, $e^*$, due to capacity constraints whenever $e^* < x_{t+1} - \overline{h} = z_t f(e_t) - \overline{h}$. Therefore, period $t$ expectations of escapement in period $t+1$ are given by

$$E_t(e_{t+1}|e_t = e^*) = f(e^*)\Phi \left( \frac{\overline{h} + e^*}{f(e^*)} \right) + \left( 1 - \Phi \left( \frac{\overline{h} + e^*}{f(e^*)} \right) \right) \left[ \int_{\frac{\overline{h} + e^*}{f(e^*)}}^{B} z \Phi(z) f(e^*) dz - \overline{h} \right]. \quad (44)$$

Given that the growth function $f(\cdot)$ is concave and $\left( 1 - \Phi \left( \frac{\overline{h} + e^*}{f(e^*)} \right) \right) > 0$, the expected stock size in period $t+2$ at time $t$ is bigger in the presence of capacity constraints. The argument holds for all time periods since the growth function is time invariant. As a result, failure to account for renewable resource harvesting constraints leads to larger future expected stock sizes. ■

If harvesting constraints bind, then the resource stock has a larger rebuilding stock which in turn leads to larger expected future resource stocks.

Another result that follows from the presence of capacity constraints is a change in the form of the escapement rule. Upon adding the capacity constraint the problem no longer exhibits “state independent control” in a Costello and Polasky (2008) sense, as the following lemma shows:

Lemma 1. The presence of non-trivial capacity constraints as in equation (43) in conjunction with the maximization problem in equation (40) imply that equation (40) does not exhibit state independent control.
Proof. Assuming an interior solution, in order for equation (40) to exhibit state independent control, the first order condition of equation 3 must be independent of $x_t$. The first order condition of equation (40) is

$$-Q'(e_t) + \delta E_t \left[ \frac{\partial V_{t+1}(x_{t+1})}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial e_t} \right] = 0$$  \hspace{1cm} (45)

To exhibit state independent control, we must show that equation (45) is independent of the stock variable $x_t$ for interior solutions. By inspection, the constraint in equation (??) shows that $e_t < x_t - \overline{h} \forall t$. As such, the first term in equation (45) is a function $x_t$ in the case that the capacity constraint may bind.

The implications of state dependent control is that a constant escapement rule will, in general, no longer be optimal. This is a different result than found in Costello and Polasky (2008) and Reed (1979). Deriving the form of an optimal harvesting rule under a general remuneration share rule is beyond the scope of this paper, but clearly further research is needed.

8 Conclusion

The findings here suggest that share remuneration has important industry level implications in renewable resource industries. Share remuneration distorts the rate at which benefits accrue to firms thereby affecting the entry and exit decisions of firms so long as the exploitable resource stock is subject to some intertemporal variation. Policy instruments in place that were constructed under the assumption of fixed wage payments can lead to further economic inefficiencies. Further, there is no one-size-fits-all regulatory regime in a share economy as applied to renewable resources. Rather, a regulator needs to account for the specific type of remuneration structure that exists in the industry and property rights regulation need to be enforced in conjunction with taxes or subsidies to ensure first best outcomes, as noted in the revenue sharing case in ITQ fisheries by Hannesson (2007). In the calibration exercise using data from the North Pacific albacore tuna longline fishery a subsidy of roughly $1681/vessel would be needed to reach optimal investment levels if an ITQ management regime was implemented.

There could be ecological gains for the renewable resource stock attributable to share remuneration if it
leads to under-investment. The ecological stability observed in ITQ managed fisheries as observed by Costello et. al. (2008) may be partially explained by the share remuneration structure observed in fisheries, as this leads to the inability of fleets under ITQ management to catch as much resource biomass as they otherwise would have under TAC management. This could lead to increased TACs in the future in fisheries. Similarly, piece rate remuneration in forestry and share-cropping in agriculture might lead to previously unexplored ecological benefits caused by under-investment. Because share remuneration can influence investment and lead to capacity constraints in any one period, constant resource biomass escapement is no longer necessarily optimal.


9 Appendix

9.1 Part A

Proposition 2:

In a operating profit sharing regime under property rights management, labor’s expected remuneration is always above their opportunity wage regardless of the level of profit sharing at optimal fleet capacity as long as the resource harvest size varies and is dictated by a continuous and strictly monotonic cdf.

Proof: Equilibrium under property rights management in operating profit sharing remuneration is given by

\[ x[(p - c)k(1 - F(kN_{ITQ}^{op}))] = (d + r)K. \] \tag{46}

Algebraic manipulation of equation \((46)\) gives

\[ (p - c)k(1 - F(kN_{ITQ}^{op})) - (p - c)(1 - x)k(1 - F(kN_{ITQ}^{op})) = (d + r)K. \] \tag{47}

Equilibrium under property rights management in the fixed wage payment case is given by

\[ (p - c)k(1 - F(kN^*)) = (d + r)K + w. \] \tag{48}

Assume that \(N_{ITQ}^{op} = N^*\). Substituting \((48)\) into \((47)\) implies that

\[ (p - c)(1 - x)k(1 - F(kN_{ITQ}^{op})) = w. \] \tag{49}

However, expected remuneration in operating profit sharing is

\[ E[M|x] = (1 - x)(p - c) \left[ \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) + k(1 - F(kN)) \right]. \] \tag{50}

As long as \( \int_{Q_{min}}^{kN} \frac{Q}{N} f(Q)d(Q) > 0 \), it must be the case that \(E[M|x] > w\) at \(N^*\).
9.2 Part B

In this model, consider a vessel’s crew to be represented by a single agent. The agent will maximize expected utility which is an increasing function of expected remuneration and is a decreasing function of effort. Assume, then, the following function form of crew utility:

\[ E[U] = E[M|x, e] - g(e) \]

\[ = (1 - x)(p - c(e)) \left[ \int_{Q_{min}}^{kN} Qf(Q)d(Q) + k(1 - F(kN)) \right] - g(e). \]  
(51)

The crew’s problem is therefore to maximize expected utility with respect to their level of effort, \( e \). The crew’s first order condition takes the form

\[ (1 - x)(-c'(e)) \left[ \int_{Q_{min}}^{kN} Qf(Q)d(Q) + k(1 - F(kN)) \right] - g'(e) = 0 \]  
(52)

which implies the equilibrium condition

\[ (1 - x)(-c'(e)) \left[ \int_{Q_{min}}^{kN} Qf(Q)d(Q) + k(1 - F(kN)) \right] = g'(e). \]  
(53)

This familiar expression simply says that the marginal benefit of effort is equal to the marginal cost of effort. For added intuition, note that

\[ (1 - x)(-c'(e)) \left[ \int_{Q_{min}}^{kN} Qf(Q)d(Q) + k(1 - F(kN)) \right] = \frac{g'(e)}{(-c'(e))}. \]  
(54)

Assuming that \( c'(e) < 0 \), if the crew share \( (1 - x) \) increases, then the denominator on the right hand side of equation (54) must decrease. Since \( c(e) \) was assumed to be decreasing and strictly convex, that implies that \( c'(e) \) will be becoming less negative as effort increases; e.g., \( c'(e) \) approaches zero as \( e \to \infty \). As a result, \( -c'(e) \) will be decreasing in \( e \). This is an intuitive result: as the crew is paid a larger share of the boats profit, they work harder to reduce operating costs. This in turn increases overall profits which may or may not increase the incentive of the quota owner to over-invest; it depends on what share of the increased profits accrue to them versus the crew.\(^{28}\)

\(^{28}\)Note that the tradeoff between income and substitution effects for income famous in New York taxis is not present here. The reason is that within season catch is not modeled as occurring stochastically. A richer model might include such counterintuitive behavior.
The type of feedback discussed above implies that increasing the scale wage of the crew will detract profits from the boats owner directly, but the feedback effect which occurs through effort will mitigate that effect.

References


