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Impact of property rights on labor contracts in commercial fisheries

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ABSTRACT

Property rights are increasingly utilized for environmental and resource management: in fisheries these market-based approaches take the form of individual transferable quotas. This paper studies labor contracts in fisheries governed by individual transferable quotas (ITQs). Previous literature on labor contracts in fisheries models the dominance of a share system of remuneration between boat owner and crew in fisheries. We extend the standard model of the labor contract to the case of ITQ fisheries to explain the share contract between crew and boat owner and the share contract between boat owner and quota owner when boat owner, quota owner, and crew are risk averse in a stochastic environment. We test this model through analysis of the Mid-Atlantic surf clam fishery and present empirical evidence of changes in contracting practices, harvest rates and shares of crew remuneration.

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1. Introduction

The persistence of share contracts in agriculture in developing countries is the focus of substantial economics literature (e.g. Refs. [3,10]). Fisheries provide a valuable context to examine labor contracting: the output is stochastic by nature, the labor efforts are usually unobservable, and total output is a product of joint effort. Worldwide, the dominant form of payment to fishery labor is a share system, in which a portion of the revenue or profit is paid to the crew in lieu of a fixed wage [26]. Across fisheries, the form of the crew share system varies between a share of gross revenues only or a share of net profit after deducting specified variable costs, and the share system exists in fisheries regardless of the degree of economic development [19]. It has been shown that when the boat owner and crew members are risk averse in a stochastic environment, crop sharing is the optimal contract, and will produce a higher effort level than a wage contract (see Refs. [32,1,27]).

Previous literature on the share system has focused on its optimality over a wage system in fisheries. Given the increasing emphasis on the use of market mechanisms for resource management in developed and developing countries, a central question is whether the crew share system will continue and whether crew shares (and hence expected incomes of fishing communities) will decrease [24,25,17]. Hannesson [14] models the effect of a share system on the level of investment in capital under ITQs and investment with optimal management, while Grafton has noted that the use of the share system may be replaced with either a wage or fixed rate payment [12,11]. However, there is no detailed treatment of the change in the share system itself after introducing ITQs.

Command-and-control regulation in fisheries, which has been criticized for inducing serious economic inefficiencies, safety hazards, and ecosystem damage, is often blamed for creating the classic "race for fish" [12,24].[2] By contrast, in fisheries managed with individual transferable quotas (ITQs), the fisherman has a guaranteed proportion of the total allowable catch (TAC), and can harvest that share throughout the season. There remain, however, questions about how a fishery will change once ITQs are implemented.

Of particular concern is the reported practice of reducing the crew's share for harvests where the boat owner leases quota to cover the harvest, a practice for which there is ample anecdotal evidence. Changes in the form and amount of crew remuneration have been documented in various fisheries which implemented ITQs including the surf clam and ocean quahog fishery [21], British Columbia halibut fishery [5] and a range of Icelandic fisheries [6,24]. The drop in crew incomes due to this practice under ITQs led to widespread tensions in Icelandic fisheries [7]. The potential redistribution of bargaining power between crew and capital

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2 Perhaps the most dramatic example of the race for fish is the infamous "Halibut Derby" in Alaska between 1990 and 1994, during which 24- to 48-h periods of frantic fishing led to accidents, loss of gear, extreme booms and busts in the supply of halibut, and fishing-related deaths. Under ITQ management the halibut fishery is now open from March to November. Similar changes have been reported in the wreckfish [29,9] and British Columbia halibut fisheries [5].

owners has helped fuel the policy debate over the socioeconomic impact of ITQs on fishing communities.

In fisheries with ITQs, the ITQ itself is a new form of capital distinct from the vessel. We designate firms that own vessels as "boat owners", who may or may not own ITQs. One significant difference between command-and-control and ITQs is that under ITQs a firm can *sell its vessels* but *retain its ITQs*. A firm that owns ITQs but not vessels is still a significant capital owner in this fishery and can lease its ITQs to boat owners. We term this type of firm a "quota owner". Markets for leasing quota have been documented in many fisheries including those in the US [24], Iceland, Netherlands, New Zealand and Canada [15]. In New Zealand, for example, the number of leases increased from 2000 occurrences in 1986 to 16,000 occurrences in 1998, and there is evidence that the relationship between quota lease and sale prices reflects economically rationale behavior [23]. The individual's choice between owning and leasing quota is driven by the relative prices and access to financial capital, and this analysis is left for future research. In this paper we focus on contracting once the firm's portfolio of owned and leased quota is determined.

In this paper, we explore the optimal fishery contract when there are three contracting parties: crew, boat owners, and quota owners. The central contracting party is the boat owner, who negotiates bilaterally with both quota owner and labor (the crew), a standard practice in fisheries. We extend the standard model of labor contracts in fisheries which establishes that crop sharing is the optimal contract when boat owners and crew members are risk averse (see Ref. [27]). We maintain the basic features of this model including the production function for a single-species fishery, a normally distributed random term, and absence of market power. We introduce a third contracting party, the quota owner, into the model to study the impact of ITQ on contracting practices. The focus of our analysis is on the temporary ownership, i.e. leasing of ITQs, for two main reasons. First, the leasing of ITQs is a noted innovation in the fishing industry, which has been observed in many ITQ fisheries, but not incorporated into the standard models. Second, it is the impact of this new type of transaction on crew that is of policy interest. We simplify some of the attributes of the ITQ fishery to emphasize the basic results of the model, without loss of generality. We show that when boat owner, quota owner, and crew member are risk averse in a stochastic environment, the optimal contract has two components: a crop-sharing contract between quota owner and boat owner, and crop sharing between the boat owner and crew. This crop-sharing contract is defined mainly by two parameters: (1) a fixed rental price θ for each unit of quota that the boat owner rents from the quota owner at the very beginning of the year; and (2) a share rate α of output price paid by the boat owner to the quota owner for each unit of quota which is rented and actually used during the year.

The negotiation between boat owner, crew and quota owner is modeled in Section 2, and the crew's choice of effort under varying contracts is modeled in Section 3. Sections 4 and 5 test this model through analysis of the Mid-Atlantic surf clam fishery; Section 4 describes some of the shifts in the usage of capital and employment of labor brought about by ITQs in this fishery, and Section 5 presents empirical evidence of changes in contracting practices and harvest rates.

2. Share contracting in ITQ fisheries

Assume that at the very beginning of the year, after investigating the market demand for the output, the boat owner makes a plan for how much he is going to harvest (H) in the year. Crew members are paid a share of the harvest instead of a wage rate. If the quota he owns (q_b) is less than the amount he plans to harvest, the boat owner has to rent the remaining quota from the quota owner ($H-q_b$). Since there is an uncertainty (μ) associated with the harvest due to stochastic elements including the weather and biological parameters, it is possible for the boat owner to lease more ITQs than needed.

We assume that in addition to a fixed rental price θ for each unit of quota rented – no matter whether or not it is actually used during the year – the boat owner also pays a share (α) of output price (P) to the quota owner for each unit of rented quota that is actually used ($\mu H-q_b$) during the year. These two components form the income of the quota owner, but represent a variable cost for the boat owner. The boat owner then shares the realized revenue and this variable cost with the crew by choosing the share rate (r). The variables used in the model are listed below.

P	price of output
μ	random term associated with the output where $E[\mu]=1$ and $\mathrm{Var}[\mu] = \sigma_{\mu}^2$. Demand, production, or both can be considered as random.[3]
H	output, a function of effort level and stock of fish
L	effort level
X	stock of fish
q_b	boat owner's own quota
r	crew share of revenue and cost
θ	fixed price paid by the boat owner to the quota owner for each quota unit rented
α	share of output price paid by the boat owner to the quota owner for each quota unit rented and actually used
β_b	boat owner's distaste for income variability
β_q	quota owner's distaste for income variability
β_c	crew's distaste for income variability
δ	annual rate of return on investment in quota from selling quota
M	per-unit sale price of quota
W	opportunity cost per unit of effort by the crew
FC	fixed costs

The income (I) and utility (U) functions of the quota owner, boat owner and crew are described in Sections 2.1–2.3, respectively. The parameters (β_b, β_c, β_q) describe the respective distastes for income variability of the boat owner, crew, and quota owner. With our assumption that all contracting parties are risk averse, the parameters (β_b, β_c, β_q) are always larger than 0 but less than 1.

2.1. Quota owner

Recall that we use the term "quota owner" to designate a firm that owns quota but not vessels, and such a firm's income has two components. One is the fixed rental price paid by the boat owner for each unit of quota rented at the beginning of the year ($\theta(H-q_b)$). The other is the share of output price paid by the boat owner (αP) for each unit that is leased and actually used ($\mu H-q_b$). The random term (μ) enters the second component, the harvest, but not the first, the fixed rental rate. The first component is a payment by the boat owner for the right to use quota during the season; whether or not he actually uses the quota, he must compensate the quota owner for its opportunity cost. But the boat owner only has to share revenue with the quota owner for those units that are actually used during the year.

$$I_q = \theta(H-q_b) + \alpha P(\mu H - q_b) \tag{1a}$$

[3] We follow the assumption made by Plourde and Smith [27] about the distribution of the random term, because we are interested in how the introduction of ITQs changes the results of the model.

The quota owner is risk averse and has preferences given by the mean–variance utility function:

$$\begin{aligned} U_q &= E[I_q] - \beta_q \operatorname{Var}[I_q] \\ &= \alpha P(H - q_b) + \theta(H - q_b) - \alpha^2 P^2 H^2 \beta_q \sigma_\mu^2 \end{aligned} \tag{1b}$$

2.2. Boat owner

A boat owner receives income from harvests (H) sold at price P and pays the crew a share of this revenue (r). If the boat owner harvests more than the quota owned, then the boat owner must cover the surplus harvest by leasing quota through a contract with a quota owner [$\alpha P(\mu H - q_b) + \theta(H - q_b)$]. As stated in the introduction, there is evidence that in ITQ fisheries the crew pays a portion of the cost of leasing quota. The share of the cost of leasing quota that is not covered by the crew is $(1 - r)$. Fixed costs are subtracted from the boat owner's income (FC). The boat owner then receives

$$I_b = (1 - r)P\mu H - (1 - r)[\alpha P(\mu H - q_b) + \theta(H - q_b)] - \mathrm{FC} \tag{2a}$$

Eq. (2a) states that the boat owner's income is equal to his share of the realized revenue (after the crew share), minus fixed costs and his share of variable cost (from leasing quota). The associated preference function is

$$\begin{aligned} U_b &= E[I_b] - \beta_b \operatorname{Var}[I_b] \\ &= (1 - r)[PH - \alpha P(H - q_b) - \theta(H - q_b)] \\ &\quad - \mathrm{FC} - (1 - r)^2 (1 - \alpha)^2 P^2 H^2 \beta_b \sigma_\mu^2 \end{aligned} \tag{2b}$$

2.3. Crew

The crew receives a share of the revenue from the harvest ($rP\mu H$). The cost of leasing the ITQs is shared with the crew ($r[\alpha P(\mu H - q_b) + \theta(H - q_b)]$). The crew income is then

$$I_c = rP\mu H - r[\alpha P(\mu H - q_b) + \theta(H - q_b)] \tag{3a}$$

The expression of the preference function for the crew income function in Eq. (3a) is

$$\begin{aligned} U_c &= E[I_c] - \beta_c \operatorname{Var}[I_c] = r[PH - \alpha P(H - q_b) - \theta(H - q_b)] \\ &\quad - r^2 (1 - \alpha)^2 P^2 H^2 \beta_c \sigma_\mu^2 \end{aligned} \tag{3b}$$

Below we present the solution to this model, and details are in the Appendix. The optimization problem is for the boat owner to maximize his utility (2b) subject to the constraints that both the quota owner and the crew accept their respective contracts. The boat owner guarantees a fixed level of utility to the crew and quota owner to induce them to participate in the contract.

The participation constraint of the quota owner is

$$\begin{aligned} &\overline{U}_q = \delta M(H - q_b) = \alpha P(H - q_b) + \theta(H - q_b) - \alpha^2 P^2 H^2 \beta_q \sigma_\mu^2 \\ &\quad \Rightarrow \alpha P(H - q_b) + \theta(H - q_b) = \alpha^2 P^2 H^2 \beta_q \sigma_\mu^2 + \delta M(H - q_b) \end{aligned} \tag{4}$$

This constraint states that the contract arrangement should compensate the quota owner's opportunity cost of leasing quota. This opportunity cost is measured by the annual return on investment from selling the quota at the very beginning of the year. There is no random component because the quota owner loses the ability to sell the quota, whether or not it is actually used during the year.

The analogous participation constraint of the crew member is

$$\begin{aligned} &\overline{U}_c = WL = r[PH - \alpha P(H - q_b) - \theta(H - q_b)] - r^2 (1 - \alpha)^2 P^2 H^2 \beta_c \sigma_\mu^2 \\ &\quad \Rightarrow r[PH - \alpha P(H - q_b) - \theta(H - q_b)] = r^2 (1 - \alpha)^2 P^2 H^2 \beta_c \sigma_\mu^2 + WL \end{aligned} \tag{5}$$

This constraint states that crew's utility from participating in this contract arrangement equals what they could get from their next best available alternative.

There are four choice variables in this case: effort level (L), fixed rental price of quota (θ), share of output paid to quota owner (α), and crew share of revenue and variable cost (r). Substituting the participation constraints (4) and (5) into the boat owner's utility function and rearranging yields

$$\begin{aligned} U_b &= PH - \delta M(H - q_b) - WL - \mathrm{FC} \\ &\quad - P^2 H^2 \sigma_\mu^2 \left[\alpha^2 \beta_q + r^2 (1 - \alpha)^2 \beta_c + (1 - r)^2 (1 - \alpha)^2 \beta_b\right] \end{aligned} \tag{6}$$

The value of α and r that maximizes U_b will be the solution to:

$$\operatorname{Min} D = \alpha^2 \beta_q + r^2 (1 - \alpha)^2 \beta_c + (1 - r)^2 (1 - \alpha)^2 \beta_b \tag{7}$$

The first-order conditions of Eq. (7) yield

$$r^* = \frac{\beta_b}{\beta_b + \beta_c} \tag{8a}$$

$$\alpha^* = \frac{r^2 \beta_c + (1 - r)^2 \beta_b}{\beta_q + r^2 \beta_c + (1 - r)^2 \beta_b} \tag{8b}$$

Substituting r^* into Eq. (8b) yields α^*:

$$\alpha^* = \frac{r^2 \beta_c + (1 - r)^2 \beta_b}{\beta_q + r^2 \beta_c + (1 - r)^2 \beta_b} = \frac{\beta_b \beta_c}{\beta_q (\beta_b + \beta_c) + \beta_b \beta_c}$$

From this expression, we notice that α^* is always between 0 and 1. It is equal to 0 if and only if β_b or β_c is zero or both of them are zero – that is, if the boat owner or crew is risk neutral or both of them are risk neutral. Since we have assumed that both are risk averse, α^* will not be zero. This implies that whenever production is feasible, a share contract between boat owner and quota owner is optimal. Note that the optimal quota share parameter α^* and optimal harvest share parameter r^* are both independent of market variables such as output price and effort level; they are purely determined by the risk aversion parameters of boat owner, crew, and quota owner.

Previous literature showed that in a stochastic production environment share contracts will be optimal.[4] The model presented here extends this result to the case of ITQ fisheries. The results show in ITQ fisheries, a share contract between crew and boat owner will persist, and a share contract between boat owner and quota owner will emerge. This model explains anecdotal evidence of the emergence of share contracts under ITQs.

3. Crew effort under an ITQ share contract

This section compares the crew's effort level, under a crop share contract, over trips differentiated by quota ownership: (1) trips using the boat owner's own quota, where boat owner and crew share the gross revenue; and (2) trips with leased quota, where boat owner and crew share both revenue and the cost of leasing quota. In this section, we assume a deterministic harvest function to illustrate the incentives created by share contracts in ITQ fisheries. The objective is to show how effort level differs between these two types of trips.

[4] The optimal solution r^* (share between boat owner and crew member) to our model where there are three contracting parties is the same as the optimal solution r^* in Plourde and Smith [27] where there are only two contracting parties including boat owner and crew member.

3.1. Trips with boat owner's ITQs

For a given stock of fish (X) the amount of harvest (H) depends on the effort level of crew (L). For trips in which the boat owner uses his own ITQs for the harvest, the utility functions of boat owner and crew can be expressed as

$$U_{\mathrm{b}} = PH(L,X) - rPH(L,X) - \mathrm{FC} \tag{9a}$$

$$U_{\mathrm{c}} = rPH(L,X) - C(L) \tag{9b}$$

where $C(L)$ shows the disutility of the crew from effort. As in the previous section, there is a participation constraint in which the boat owner guarantees a reservation utility of $\overline{U}$ to the crew. Then the boat owner solves

$$\text{Max } U_{\mathrm{b}} = PH(L,X) - rPH(L,X) - \mathrm{FC} \tag{10}$$

subject to :

$$U_{\mathrm{c}} = rPH(L,X) - C(L) = \overline{U}$$

Substituting the constraint into the objective function and solving the first-order condition gives

$$P = \frac{C_L}{H_L} \tag{11}$$

This equation indicates that the optimal effort level is achieved when the marginal output value of an extra unit of effort is equal to the crew's marginal disutility from that effort. The optimal effort level, L^*, is the solution to this first-order condition.

3.2. Trips with leased ITQs

In contrast, for trips where leased quota is used, the utility functions of boat owner and crew reflect that a part of the revenue from harvests covers the costs of leasing. The utility functions are

$$U_{\mathrm{b}} = (1-r)PH(L,X) - (1-r)\theta H(L,X) - \mathrm{FC} \tag{12a}$$

$$U_{\mathrm{c}} = rPH(L,X) - r\theta H(L,X) - C(L) \tag{12b}$$

Again, we assume that the boat owner guarantees a reservation utility of $\overline{U}$ to the crew. The boat owner's optimal choice problem becomes

$$\text{Max } U_{\mathrm{b}} = (1-r)PH(L,X) - (1-r)\theta H(L,X) - \mathrm{FC} \tag{13}$$

subject to :

$$U_{\mathrm{c}} = rPH(L,X) - r\theta H(L,X) - C(L) = \overline{U}$$

The first-order condition for this optimization is

$$P - \theta = \frac{C_L}{H_L} \tag{14}$$

The optimal effort level, L^{**}, is the solution to the above condition.

To compare the effort level over these two types of trips, we differentiate C_L/H_L with respect to L. The standard assumption about production indicates that $H(L,X)$ is increasing in L and concave, and $C(L)$ is increasing and convex, which means the marginal output from effort is decreasing while the marginal disutility of effort is increasing. That is

$$H_L > 0, \quad H_{LL} < 0, \quad C_L > 0, \quad C_{LL} > 0$$

Based on these assumptions, we can sign the above equation:

$$\frac{\partial \frac{C_L}{H_L}}{\partial L} = \frac{C_{LL}H_L - H_{LL}C_L}{H_L^2} > 0 \tag{15}$$

This result indicates that C_L/H_L is an increasing function of L.

Because C_L/H_L is increasing over L, and $P > P - \theta$, the optimal effort level in the first case (boat owner's own quota) is higher than in the second case (leased quota). This is an intuitive result, in that the crew has to bear its share of the leasing cost in the second case.

Our model of contracting between boat owners and crew makes three behavioral assumptions that are consistent with the economic literature. First, crew members have declining utility with respect to effort. Second, in order to retain crew the contract must provide at least enough utility as crew would receive in their next best alternative. This participation constraint states that the crew earns at least their reservation utility of $\overline{U}$. Third, the contract offered to the quota owner must provide at least the minimum utility the quota owner would receive in their next best alternative. The boat owner then maximizes his utility subject to these constraints by choosing three variables: the fixed rental price of a quota, the share of the harvest paid to the quota owner, and the share of harvest costs shared by the crew. Conceptually this optimization means that the boat owner weighs the benefits of passing the cost of leasing the quota on to the crew with the cost of the reduced crew effort. These three variables completely describe the contract offered to the crew who then has one choice variable, the effort level. The first-order condition for the boat owner shows that it is optimal for the boat owner to accept the lower effort level of the crew, because it allows the boat owner to pass along the cost of leasing the quota.

There are two critical results from this model. First, under ITQs, the share system incorporates both the agreement between boat owner and crew and the agreement between boat owner and quota owner. Second, because the crew shares the cost of leasing quota, their incentive is to harvest at a lower rate than on a trip where the quota is owned by the boat owner. This result is similar to that in agricultural share contracts [2].

While this model explains why deducting the cost of the leasing of quota is a stable arrangement in the case of an ITQ fishery, one could then contemplate if ITQs could create the conditions for optimality of a wage system instead of the traditional share system.[5] To address this question, one needs to consider the two modeling perspectives used to explain the share system, risk sharing [27,32] and moral hazard [13,22], and then ask whether the introduction of ITQ changes the conditions of these models. In the case of risk sharing we feel that the change to ITQs is unlikely to create such a shift to a wage system, because boat owners' preferences are pre-determined and arguably exogenous to the regulatory setting. In the moral hazard approach making the crew's payment dependent on the harvest addresses the problem that the crew has the incentive to shirk because his effort is not observed or verifiable. While ITQs may change the pace of harvesting, there is no evidence that the actual fishing process, or the ability to verify the effort of individual crew has changed. We therefore conclude that the introduction of ITQs will change the nature of the share contract but not the motivation and thus existence of the share system.

4. Case study: Mid-Atlantic surf clam fishery

The theoretical model of firm contracting explains the share contract both between boat owner and crew and between boat owner and quota owner (Eqs. (8a) and (8b)). In addition, the model of crew behavior in Section 3 indicates that the optimal effort level on trips with leased quota should be lower than that on trips with the boat owner's quota.

We verify these models using evidence gathered by extensive field interviews and harvest data in the Mid-Atlantic surf clam fishery, which is described in this section. The data used to estimate the models in this paper are from the National Marine Fishery

[5] The authors thank an anonymous reviewer for posing this question.

Service logbook reporting system, which documents every harvesting trip taken by every vessel.[6]

4.1. Changes in capital utilization

In 1976, the Mid-Atlantic Fishery Management Council restricted allowable fishing time in the surf clam fishery and implemented a limited access system. By the mid-1980s, however, rapid growth in harvesting capacity and resulting inefficiencies led to a proposal to implement a property rights system; from the mid-1980s to 1988, council meetings were dominated by the contentious issue of distributing quotas among the industry participants. The ITQ allocation formula was finalized in 1988,[7] and the first full year of tradable property rights was 1991.

One long-term benefit associated with the ITQ system is the reduction of excess capital. From Fig. 1, it is evident that the number of vessels active in harvesting surf clams increased from 1985 to 1990. However, there was a dramatic reduction in the number of vessels in 1991, falling from 39 in 1990 to 26 in 1991. This reduction in fishing capital reflects a significant change in industry structure resulting from the anticipated policy change. In the years following 1991, the number of vessels continued to slowly decline.

The reduction in capital in the fishery was concurrent with an increase in time of fishing per vessel. Of the independent vessels that harvested before and after ITQs, 75% increased their annual total hours at sea in 1995 compared to that in year 1990. The percentage increase in time spent at sea ranges from a low of 16% to a high of 1100%.

4.2. Impact of ITQs on crew

We are specifically concerned with the impact of this change on crews and crew contracts. Vessel logbooks record the number of crew used per fishing trip. By aggregating the number of crew recorded per vessel, we found that the reduction of vessels in the fishery significantly reduced the total labor employed by the sector. In 1990, 155 crew members were employed in this sector; this number fell to 98 in 1993, 83 in 1995, and 34 in 1999. These numbers reflect a dramatic decline in the potential employment for fishing crew in this sector, due to the consolidation of capital. This is consistent with our expectation that the total crew in the sector will be reduced by the introduction of ITQs, since some vessels exit the market by selling their quota.

Other researchers have posited that those vessels remaining in the sector could substitute additional fishing time for crew members, because the elimination of the "race for fish" creates more orderly fishing conditions [11]. However, this substitution for employment was not significant in the surf clam fishery; of the 12 vessels that were active in both 1990 and 1995, only one vessel increased its crew size and the remaining kept crew size constant over that period.

Under the payment system prior to ITQs, crew members shared gross revenues with the boat owner, a typical arrangement allotting

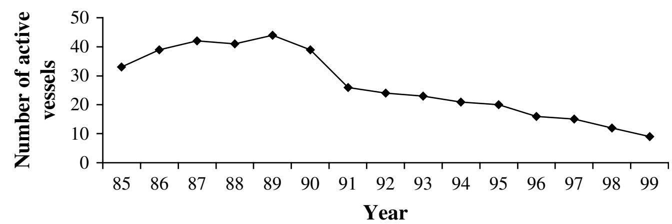

Fig. 1. Active vessels, 1985–1999.

1/3 of the gross revenues to the crew [16]. However, with the introduction of ITQs, this system changed, with boat owners generally deducting the cost of leasing quota from the gross revenues, and then sharing the net revenues with the crew. A typical arrangement now is for the boat owner to pay half of the gross revenues to the quota owner, and then share the remaining half with the crew. In this case, the crew share of net revenues is still 1/3, but its actual share of gross revenues is reduced to 1/6.

However, if ships spent more time at sea and ITQs increased fishing efficiency, crew members could still be better off under the new system. Table 1 summarizes the changes in per-vessel crew payments from 1992 to 1999, relative to the same set of vessels in 1990. The first row is the count of vessels operating in that year that were also operating in 1990. The second row is the count of vessels whose total crew income in that year was greater than the total crew payment for the same vessel in 1990. Of the 19 vessels active in the sector in both 1990 and 1992, crew income from harvesting surf clams increased in five vessels and decreased in 14 vessels: approximately one-quarter of the boats operating in both periods saw crew payments increase relative to 1990 while three-quarter saw them decline relative to 1990. By 1999 the proportion of vessels with total crew payments that were higher than in 1990 had reached 80%. The mean total payment to crew for harvesting surf clams was $77,319 in 1990 (standard deviation of $39,441), while the mean in 1995 was $115,755 (standard deviation of $97,740).[8]

Standard models of ITQs in fisheries predict a reduction of overcapitalization, consolidation of capital, and efficient use of remaining capital. These changes were observed in the surf clam fishery after the introduction of ITQs. In summary, ITQs produced a significant decrease in capital in the fishery, but an increase in the mean amount of time vessels spent at sea. For crews, ITQs led to a reduction in total employment in the fishery, but an increase in the mean payment for harvesting surf clams.

In addition to the changes predicted by standard models, the model presented in Sections 2 and 3 predicts changes in contracting in the fishery. Empirical evidence of these changes is presented in the next section.

5. Empirical evidence of share contracts

5.1. Emergence of new contractual relationships

This fishery consists of three types of participants: independent firms, vertically integrated firms and horizontally integrated firms (for discussion of participant types see Ref. [20]). For our empirical analysis we considered those vessels owned by independent firms, firms that were neither vertically integrated with the processing sector nor horizontally integrated with other fishing vessels. In field interviews, participants reported that independent firms consistently subtract the cost of a quota only if the quota is owned

[6] Compliance with reporting regulations is rated as high [18].

[7] The National Oceanic and Atmospheric Administration approved the final version of the tradable property rights program in 1990. See Ref. [16]. The surf clam allocation included vessel catch (80%) and vessel capacity (20%). For vessels harvesting surf clams, the historical catch was equal to the vessel's total harvest over 1979–1988 (counting the years 1985–1988 twice and dropping the vessel's worst 2 years). Each vessel's catch ratio was the vessel's historical catch divided by the sum of all vessels' historical catch. The vessel's cost factor was equal to the product of the vessel's length, width and volume. The vessel's cost ratio was equal to the vessel's cost factor divided by the sum of the cost factors over all vessels. The vessel's initial surf clam allocation, as a percentage of the total harvest, was 0.8 (catch ratio) + 0.2 (cost ratio).

[8] Total payments in both years are in 1999 real dollars.

Table 1
Change in payment to vessel crew, 1992–1999

	1992	1993	1994	1995	1996	1997	1998	1999
Count of vessels	19	16	13	12	9	8	8	5
Count of vessels with higher payments relative to 1990	5	5	6	8	5	5	4	4

Table 2
Descriptive statistics for harvest rates over two types of trips, 1992–1999

	N	Mean	SD	Median	IQR
Leased quota	1960	72.79	39.79	56.00	45.20
Own quota	2412	80.58	54.25	64.00	55.45

by another distinct firm. This case of an external contract is depicted in our model. In contrast, the integrated firms may deduct the cost of leasing quota from the boat's trip under two cases: when the firm leases the quota from another distinct firm (external contract or lease), or when the quota is owned by the same firm but was allocated to a different vessel (internal contract or lease). This pattern of external (between distinct firms) and internal (between units of the same firm) trades and contracts has been found in industries in addition to the surf clam fishery [4]. We decided to limit the analysis to the case of the independent firms for two reasons. First, the model of combining external and internal contracting is sufficiently complex to warrant a paper in and of itself and is left for future research. Second, based on interviews, we felt confident that an independent firm subtracts the cost of leasing only if there is an external contract. Therefore, without making assumptions about the unobserved contract (internal or external), the data available to researchers allow us to identify those trips for which the price of the quota is deducted in the case of an external contract by an independent firm.

Section 2 presents a model that predicts that a share contract between quota owners and boat owners will emerge in an ITQ fishery. Extensive interviews of surf clam harvesters revealed that transactions for surf clam ITQs are often bilateral trades between industry participants rather than transactions in a standard market. For transactions between two different firms (external transactions), contracts specify how the price per bushel of clams is split between the boat owner and the quota owner, with the boat owner typically earning 50–60% of the output. For example, if an independent fishing firm harvests using a quota owned by a clam processor, the independent firm receives $5–6 per cage of clams out of the $10 market price [21,20,28,24]. This type of agreement and its contribution to disputes over the welfare effects of ITQs has been documented in other fisheries as well [7].

In addition, our model predicts that boat owners can pass some of the cost of leasing ITQs onto the crew and still meet the participation constraint. Indeed, empirical evidence shows that by 1994 a majority of harvesting firms (boat owners) had implemented a new share system, where the cost of leasing quota was deducted from gross revenues before sharing with the crew. The following section compares harvest patterns between the trips with quota owned by the boat owner's (own quota) and trips with quota leased from a quota owner (leased quota), in order to test the model developed in Section 3. As predicted, trips with the boat owner's own quota tend to have a higher effort level than trips with leased quota.

5.2. Changes in crew effort

Labor effort is a classic case of an unobservable or "hidden" action in a moral hazard problem [30]. In our case the observable outcome correlated with the effort is the harvest rate. We feel confident in comparing harvest rates over trips with owned and leased quotas for purposes of empirical analysis because (1) the major capital input, the vessel with its embedded technology, is unchanged between trips; (2) the resource is currently harvested at an estimated maximum sustainable yield and can be considered stable between trips; (3) the time-frame for comparison is a matter of days which reduces other confounding effects.

From 1992 to 1999, a total of 4372 fishing trips were reported, of which 45% used leased quota. The mean harvest rate (in bushels per hour) for trips with own quota is 11% higher than for trips with leased quota (see Table 2). In addition to having a higher mean and median, the harvest rate of trips with own quota displayed greater variability than for trips with leased quota (standard deviation of 54.25 compared to 39.79 bushels per hour and interquartile range (IQR) of 55.45 and 45.20). The period with the greatest deviation between harvest rates was 1996–1999, when the mean harvest rates of trips with owned quota were 29% higher than for trips with leased quota.

Fig. 2 shows that harvest rates for trips using own quota overtook rates for trips using leased quota in 1994, the year by which a majority of boat owners had adopted the new share system (where quota costs are subtracted from gross revenues before sharing with crew). From then through 1999, mean harvest rates using the boat owner's own quota were always higher than mean harvest rates using quota leased from the quota owner. From 1992 to 1993, before the general adoption of the new contracting system, harvest rates using own quota were actually lower than those using leased quota. This preliminary result is consistent with the prediction in Section 3 that effort levels will be higher for trips using own quota than for trips using leased quota.

We used a paired t-test to verify that these differences between mean harvest rates are statistically significant, pooling all data from 1994 to 1999. There are a total of nine vessels that harvest in each year from 1994 to 1999 using both own and leased quotas (in different trips). By matching the mean harvest rate of both types of trips based on the individual vessel, we rejected the null hypothesis that mean harvest rates for the two types of trips are equal (t-value $= 2.78$) at 5% significance level. It is important to clarify that these changes are independent of a recent population decline in the southern range of the surf clam habitat. The period of decline was 1999–2002 and has been attributed to warmer waters in this region [33]. We do not believe that this decline affects our results for two reasons. First, our analysis is focused on the period prior to the decline (1994–1999). Second, to test our hypothesis of difference in rate of harvest for trips with leased versus owned quotas, we are interested in variation between trip types, rather than the changes over time.

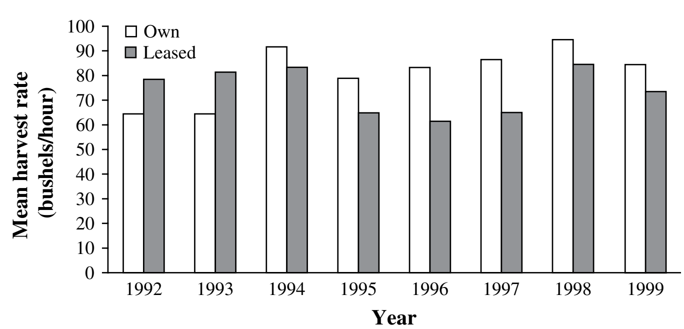

Fig. 2. Annual mean harvest rate by ITQ ownership.

5.3. Regression results

The previous section showed that the mean harvest rate of trips with own quota tends to be higher than that with leased quota. Our regression analysis includes trips of the 17 vessels owned by firms that both leased and owned quota from 1992 to 1999 ($n=2797$). Results are reported in Table 3. The dependent variable is the harvest rate (bushels of surf clams per hour). Explanatory variables include an indicator for trips with quota that are owned by the boat owner and for which the crew receives the full 1/3 share of the revenue, dummy variables for season the trip was taken and a dummy variable for each of the vessels in the sample. The dummy variable for the vessel captures the difference in the harvest rate due to differences in the capital (e.g. age and size of vessel), any geographical variation in surf clam abundance near the vessel's primary port and skill of the captain. To preserve confidentiality the boat identifiers are suppressed: instead we differentiate the vessels by dummy variables for the 17 active vessels (randomly assigned). The base case is harvests in the winter with leased quota by vessel 17. The model as a whole is statistically significant (F-statistic equals 164.32) and explains more than half of the observed variation in the harvest rate (adjusted R-square is 0.5388). There was no significant change in the stock of surf clams over the period of interest [33].

The coefficient for trips taken with quota owned by the boat owner ("own") is 5.42 and is statistically significant (p-value $=$ 0.003). On average, trips taken with quota owned have a harvest rate that is 5.42 bushels per hour greater than trips with leased quota. To put this value in context, consider the fact that these results indicate that the difference in harvest rates between trips with owned versus leased quota is slightly larger than the difference in harvest rates between winter and fall, and substantially greater than the difference in harvest rates between winter and spring or summer. Furthermore, for the 17 vessels in these data the difference in harvest rates between trips with owned quota and the harvest rate on leased trips ranges from a minimum of 2.8% to a maximum of 19.4% and has a mean of 8%. In other words, on average the trips with owned quota had a harvest rate that was almost 8% higher than those trips with leased quota. This result provides substantial empirical support for the prediction of our model, on trips with leased quota the crew share the cost of leasing the quota and in response select a lower effort. The observable outcome of lower effort level is a lower harvest rate.

Table 3
Regression results

Variable	Coefficient	Standard error	P-value
Constant**	28.01	4.15	0.000
Own**	5.42	1.79	0.003
Spring	1.07	2.16	0.621
Summer	0.09	2.10	0.965
Fall*	5.21	2.05	0.011
Boat effects			
Boat 1**	97.12	6.11	0.000
Boat 2**	21.07	5.98	0.000
Boat 3**	52.22	4.38	0.000
Boat 4**	18.55	4.62	0.000
Boat 5**	75.47	3.64	0.000
Boat 6**	49.23	5.86	0.000
Boat 7**	25.30	3.63	0.000
Boat 8**	81.14	4.58	0.000
Boat 9**	41.23	4.75	0.000
Boat 10**	11.43	5.36	0.033
Boat 11**	64.20	4.51	0.000
Boat 12**	163.62	4.15	0.000
Boat 13**	58.81	4.56	0.000
Boat 14**	88.21	6.90	0.000
Boat 15**	48.83	5.11	0.000
Boat 16**	57.61	8.00	0.000

*Significant at the 5% level.
**Significant at the 1% level.

6. Summary and conclusions

In evaluating alternative regulatory approaches to fisheries, it is critical to consider all of the ways in which industry participants will adapt to regulatory change. This paper provides a mathematical model to explain the contracting relationships under ITQs and subsequent effort levels in a fishery by presenting an economic model and then testing this model in the Mid-Atlantic surf clam fishery.

Under ITQs, when boat owner, quota owner, and crew are risk averse in a stochastic environment, share contracts between crew and boat owners and share contracts between quota owners and boat owners are economically rational. In addition, boat owners can defray the cost of leasing ITQs by sharing this cost with the crew, while still meeting the crew's participation constraint. Under these types of contracts, where the cost of leasing quota is shared between boat owner and crew, the crew will expend a lower effort level than on trips where the quota is owned outright by the boat owner. The consequence of this hidden action is observable as a higher harvest rate for trips using the boat owner's own quota than for trips using leased quota, as confirmed by an analysis of the surf clam fishery.

Environmental regulations using market incentives, such as ITQs, are increasingly popular internationally. As described in this paper, the persistence and form of share contracts under these policies could have important implications for the labor sector.

Appendix

Negotiation of contract

The optimization problem in this contract is for the boat owner to maximize his utility subject to the participation constraints of both quota owner and crew. That is, maximize

$$U_\mathrm{b} = E[I_\mathrm{b}] - \beta_\mathrm{b}\,\mathrm{Var}[I_\mathrm{b}] = (1-r)[PH - \alpha P(H-q_\mathrm{b}) - \theta(H-q_\mathrm{b})] - \mathrm{FC} - (1-r)^2(1-\alpha)^2P^2H^2\beta_\mathrm{b}\sigma_\mu^2$$

subject to:

$$\overline{U}_\mathrm{q} = \delta M(H-q_\mathrm{b}) = \alpha P(H-q_\mathrm{b}) + \theta(H-q_\mathrm{b}) - \alpha^2P^2H^2\beta_\mathrm{q}\sigma_\mu^2$$
$$\Rightarrow \alpha P(H-q_\mathrm{b}) + \theta(H-q_\mathrm{b}) = \alpha^2P^2H^2\beta_\mathrm{q}\sigma_\mu^2 + \delta M(H-q_\mathrm{b}) \quad (a)$$

The expected value of the quota owner's return from leasing his quota must be sufficient to compensate him for the return he would obtain by selling the quota, plus the risk associated with the uncertain output. The utility function for the crew is

$$\overline{U}_\mathrm{c} = WL = r[PH - \alpha P(H-q_\mathrm{b}) - \theta(H-q_\mathrm{b})] - r^2(1-\alpha)^2P^2H^2\beta_\mathrm{c}\sigma_\mu^2$$
$$\Rightarrow r[PH - \alpha P(H-q_\mathrm{b}) - \theta(H-q_\mathrm{b})] = r^2(1-\alpha)^2P^2H^2\beta_\mathrm{c}\sigma_\mu^2 + WL \quad (b)$$

The expected value of the crew's return from joining the fishing trip must be sufficient to compensate them for their opportunity cost (the wage in next best employment), plus the risk associated with the uncertain output.

There are four choice variables in this case: effort level (L), fixed rental price of quota (θ), crew share of revenue and variable cost of crew (r), and share of the output price of quota owner (α). Substituting constraints (a) and (b) into the boat owner's utility function, we get

$$U_b = PH - \alpha^2 P^2 H^2 \beta_q \sigma_\mu^2 - \delta M(H - q_b) - r^2(1-\alpha)^2$$
$$P^2 H^2 \beta_c \sigma_\mu^2 - WL - FC - (1-r)^2(1-\alpha)^2 P^2 H^2 \beta_b \sigma_\mu^2$$
$$\Rightarrow U_b = PH - \delta M(H - q_b) - WL - FC - P^2 H^2$$
$$\sigma_\mu^2 \left[\alpha^2 \beta_q + r^2(1-\alpha)^2 \beta_c + (1-r)^2(1-\alpha)^2 \beta_b\right]$$

The value of α and r that maximizes U_b will be the solution to:

$$\text{Min } D = \alpha^2 \beta_q + r^2(1-\alpha)^2 \beta_c + (1-r)^2(1-\alpha)^2 \beta_b$$

Differentiate D with respect to α to get the first-order condition:

$$\frac{\partial D}{\partial \alpha} = 2\alpha\beta_q - 2(1-\alpha)r^2\beta_c - 2(1-\alpha)(1-r)^2\beta_b = 0$$
$$\Rightarrow \alpha\left[\beta_q + r^2\beta_c + (1-r)^2\beta_b\right] = r^2\beta_c + (1-r)^2\beta_b$$
$$\Rightarrow \alpha^* = \frac{r^2\beta_c + (1-r)^2\beta_b}{\beta_q + r^2\beta_c + (1-r)^2\beta_b}$$

Differentiate D with respect to r to get the other first-order condition:

$$\frac{\partial D}{\partial r} = 2r\beta_c - 2(1-r)\beta_b = 0$$
$$\Rightarrow r^* = \frac{\beta_b}{\beta_b + \beta_c}$$

Our result shows that the optimal choice of share value between boat owner and crew member under ITQs is the same as the general result documented by Plourde and Smith [27]. Note that the optimal parameter r^* will be independent of market variables such as wage, price, and employment [27].

Substitute $r^* = \beta_b/(\beta_b + \beta_c)$ back into α^* to get

$$\alpha^* = \frac{r^2\beta_c + (1-r)^2\beta_b}{\beta_q + r^2\beta_c + (1-r)^2\beta_b} = \frac{\beta_b\beta_c}{\beta_q(\beta_b + \beta_c) + \beta_b\beta_c}$$

From this expression, we notice that α^* is always between 0 and 1. It is equal to 0 if and only if β_b or β_c is zero – in another words, when boat owner or crew member is risk neutral. Since we have assumed that both of them are risk averse, α^* will not be zero. This means that whenever production is feasible, a share contract between boat owner and quota owner is optimal. Note that the optimal share parameter α^* is also independent of market variables such as output price and effort level; it is purely determined by the risk aversion parameters of boat owner, crew member and quota owner.

Substitute $r^* = \beta_b/(\beta_b + \beta_c)$ and $\alpha^* = \beta_b\beta_c/(\beta_q(\beta_b + \beta_c) + \beta_b\beta_c)$ back into the objective function of D to get the minimum value of D. Through simple mathematical manipulation, we can get

$$D^* = \beta_q \alpha^*$$

Substitute $D^* = \beta_q\alpha^*$ back into boat owner's utility function to get

$$U_b = PH - \delta M(H - q_b) - WL - FC - P^2 H^2 \sigma_\mu^2 D^*$$
$$= PH - \delta M(H - q_b) - WL - FC - P^2 H^2 \sigma_\mu^2 \beta_q \alpha^*$$

Let $\sigma_\mu^2 \beta_q \alpha^* = k$, the objective function now becomes

$$\text{Max}_L\, U_b = PH - \delta M(H - q_b) - WL - FC - P^2 H^2 \sigma_\mu^2 D^*$$
$$= PH - \delta M(H - q_b) - WL - FC - kP^2 H^2$$

Differentiate U_b with respect to L to get the first-order condition:

$$V_L = PH_L - \delta MH_l - W - 2kP^2 HH_L = 0$$

The second-order condition is

$$V_{LL} = PH_{LL} - \delta MH_{LL} - 2kP^2\left(H_L^2 + HH_{LL}\right) < 0$$

By the implicit function theorem, we can solve the first-order condition to get the explicit expression of choice variable $L^*(k, P, M, W, \delta)$.

Differentiate the first-order condition with respect to k, we then get

$$PH_{LL}\frac{\partial L^*}{\partial k} - \delta MH_{LL}\frac{\partial L^*}{\partial k} - 2P^2 HH_L - 2kP^2 H_L^2 \frac{\partial L^*}{\partial k} - 2kP^2 HH_{LL}\frac{\partial L^*}{\partial k} = 0$$
$$\Rightarrow \frac{\partial L^*}{\partial k} = \frac{2P^2 HH_L}{PH_{LL} - \delta MH_{LL} - 2kP^2\left(H_L^2 + HH_{LL}\right)}$$

By the second-order condition, the denominator is less than zero. We then could sign it as

$$\Rightarrow \frac{\partial L^*}{\partial k} < 0$$

Since k is an increasing function of α^*, the optimal employment and output level for a boat owner will be smaller when he faces output price sharing quota leasing than the situation when he faces the fixed rental price quota leasing.

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