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Monitoring With No Moral Hazard: The Case of Small Vessel Commercial Fishing

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On small commercial fishing vessels skippers are hired to supervise crew members, despite the fact that shirking by crew members is generally recognized not to be a problem. If the skipper is not a residual claimant, then why does he supervise? We argue in this paper that the skipper's supervisory duties are confined to the measurement of output. Output measurement occurs because each crew member's marginal product is stochastic and expected value of marginal product is not known. Since the firm must know expected value in order to set shares, a monitor is hired to conduct a statistical hypothesis test as to this parameter's value. The paper develops a theory and test of pay differentials between monitors and employees where all parties to a share contract are symmetrically uninformed about productivity. In the theoretical section a general mean-variance model of share contracting with stochastic employee-specific output, risk aversion and costly monitoring is presented. The monitoring process is treated as a sequential sampling experiment where the length of monitoring time is uncertain. Equilibrium shares are derived. Monitor-employee share differentials are shown to rise with the variance of an employee's output and the number of employees and fall with the expected value of the firm's output. The risk neutrality version of the monitor-employee share differential is tested on data obtained from small commercial fishing vessel owners on the Oregon coast. Empirical results offer strong support for the hypothesis.

INTRODUCTION

This paper is about the economics of supervision on small (2–7 crew) commercial fishing vessels. Although we employ a model of sharing provision and test it on data from the commercial fishing industry, the results of the paper are applicable to other industries and contractual arrangements. We motivate the paper with a survey of some stylized facts[1]:

(1) Employees (skippers and crew members) are paid entirely shares of the value of catch. Shares are set before the season begins;

(2) Skippers have two functions. First, they participate in the harvesting of catch along with other crew members. Second, they supervise crew members and act as intermediaries between vessel owners and crew members. Other duties include navigation, bookkeeping, buying groceries and supplies, etc. Vessel owners report that the primary duty of the skipper outside of harvesting catch is supervision of the crew;

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(3) On small vessels on-the-job shirking of crew members is generally recognized not to be a problem. The explanation for this is that due to the size of the vessel and the close proximity of crew members to each other, the skipper can very easily ascertain whether a crew member is shirking;

(4) Skippers almost always get larger shares than crew members. The difference between the skipper and crew share (the "skipper-crew share differential") varies across species, vessel sizes and ports. Vessel owners report that the share differential primarily reflects a "premium" paid for supervisory services;

(5) The variability of trip-by-trip catch over the season for a single boat varies across vessel sizes and species;

(6) Crew shares are sticky downwards. If a crew member is found to be performing below expectation during the season, he is usually fired rather than having his share cut. Thus the main type of evidence of mid-season monitoring is turnover (although on some boats mid-season alteration of crew shares is observed);

(7) There is typically a dispersion of shares across crew members for a single boat, indicating that vessel owners attempt to reward each crew member with a share reflecting his particular level of productivity. This dispersion of shares is evidence of sorting.[2]

These observations inspire two questions: (1) if cheating is not a problem, but the skipper's premium over the crew share primarily reflects compensation for supervision, what is the reason for supervision on vessels?; (2) what are the factors explaining cross-sectional differences in skipper-crew share differentials? This paper argues that the answers to these two questions are rooted in a symmetric information view of monitoring, where the stochastic nature of output requires the firm to gather information about employees on-the-job.

We briefly review three strands of literature relevant to our inquiry: (1) monitoring; (2) output variability and compensation in piece/share contracts; (3) pay differentials between employees.

Monitoring

Alchian and Demsetz [1] suggest two reasons for why firms expend resources for the monitoring of employees[3]: (1) the enforcement of contracts; (2) the measurement of output. The former we will refer to as the "asymmetric information" (or "principal-agent") approach, and the latter as the "symmetric information" approach.

The asymmetric information approach has been the traditional approach to analyzing the firm's monitoring activities. The worker (agent) has more information about his on-the-job performance than the firm (principal). Therefore, the worker has discretionary ability to vary his productivity. The firm will hire a monitor[4] to discipline employees and the monitor's compensation will be the net gains in productivity from reduced shirking. Problems associated with moral hazard in share contracting have been discussed by Cheung [4], Eswaran and Kotwal [7, 8], Lucas [11], Pencavel [13], Stiglitz [14, 15] and Sutinen [16, 17].

The symmetric information approach to monitoring has received less attention in the labor literature and no attention in the share contracting literature. This approach suggests that even in the absence of cheating, firms must sample employee performance on-the-job. For example, if an employee's output is variable and average performance is unknown, firms must monitor performance to determine whether initial wage or share offers reflect true average performance. In addition, firms are typically uncertain about an employee's productivity across tasks at the beginning of the firm-worker match. The monitor would be compensated strictly for the sampling of performance, not for policing employees.

Output Variability

The literature on share contracting suggests that output variability affects shares because some parties to the contract are risk averse (see Cheung [4], Stiglitz [15] and Sutinen [17]). For example, Stiglitz showed in a mixed contract setting that if the variance of output rises, risk averse workers will supply labor only if risk neutral firms lower the fraction of compensation based on piece rate pay, i.e. there is an inverse relationship between the piece rate and variance. Cheung and Sutinen show that if firms are risk neutral, workers are risk averse and firms offer only share contracts, a rise in variance causes the firm's share to fall and the worker's share to rise.

Pay Differentials Between Employees

The customary explanations for pay differentials across workers within the same firm are differences in productivity and differences in risk taking. Since cheating is not a problem on small commercial fishing vessels, we can rule out residual claims as an explanation of skipper-crew share differentials. We can also rule out differential risk taking as an explanation because it could never occur in a pure (100%) share contract. For example, suppose there are two risk averse workers, A and B and A is more risk averse than B. The firm could not offer B a larger share for bearing more risk because since the contracts for both are perfectly correlated, B's contract will unambiguously dominate A's, causing the defection of A from the firm. We can exclude differential risk taking in general if firms choose the same contract for each worker. Firms can "mix" contracts by offering those workers more willing to bear risk a larger fraction of compensation based on piece/share pay. Observing pay differentials with heterogeneous contracts would be consistent with a differential risk taking hypothesis. Pay differentials with homogeneous contracts would indicate the non-existence of risk differentials across workers. In commercial fishing therefore, it is clear why all employees are offered pure share contracts: all workers (including the skipper) face the same level of risk.

Productivity differences in the harvesting of catch could partly explain share differentials between skippers and crew members but vessel owners claim on small vessels that this effect would be small. The reason is that on small vessels, skill requirements in harvesting are essentially the same across workers since workers routinely rotate across tasks. The skipper may be more productive in harvesting due to age and experience, but again vessel owners report this to be insignificant.

Our literature survey suggests that we lack a theory of symmetric information monitoring in share contracts. In addition, we lack a theory of monitoring that links output variability with supervisory-employee pay differentials. In this paper we proceed from the symmetric information approach to monitoring. Monitoring is conducted because each worker's marginal product typically varies over time and the expected value of marginal product is not known at the time of hiring. The firm must know expected value in order to set shares. A monitor is hired to estimate the expected value of each employee's marginal product. The greater is the variability of marginal product, the greater on average will be the costs of the monitoring process. This suggests a connection between the variability of marginal product and compensation to the monitor.

In the first section of the paper we develop a mean-variance model of share contracting with stochastic employee-specific output, costly monitoring and risk aversion. The model is used to derive share differentials between monitors and employees. The analysis suggests that an important explanation of cross-sectional differences in share differentials is cross-sectional differences in output variability. In the second section of the paper, the share differential is estimated using data from the Oregon commercial fishing industry. Empirical results offer strong support for our symmetric information approach to monitoring.

THE MODEL

In this section we generalize and extend the Cheung [3] share contracting model to include employee-specific output variability, explicit specification of the firm's monitoring technology and costs, and risk attitudes. We make the following assumptions:

1. The output of each worker is a normally distributed random variable[5] with unknown mean and known variance, where output varies over each of $t = 1, \ldots, T$ periods;
2. Both firm and worker are symmetrically uninformed about the employee's mean marginal product and both are fully informed about variance;
3. Workers are allowed to differ according to mean marginal product, but not in variance[6];
4. One employee (the monitor) is assigned to monitor other employees, but the monitor also participates in production;
5. The costs to the firm of monitoring are identical to the costs of hiring a monitor[7];
6. All parties to the contract have identical tastes;
7. If an employee is found to be performing below his contracted share, he is terminated rather than having his share lowered. Shares can be raised in response to observed productivity increases, however.
8. Product price is unity throughout.

The firm's problem is to formulate optimal shares of the value of output for itself, each employee and the monitor prior to production. In a world of costless information the employee's share will simply be the ratio of expected marginal product to expected total product, i.e. the share is based on *average* performance over time. If the worker's expected marginal product is not known but the firm has an opportunity to learn its value at a cost prior to the last period of production, the firm may expend resources to sample output of workers. Thus in this model the firm's particular problem is to formulate shares given uncertainty about each worker's average performance and the costs of learning about average performance. Shares will be fixed at least through the estimated length of the monitoring period.

For $j = 1, \ldots, L$ workers (including the monitor), let q_j be the jth employee's marginal product and $E(q_j)$ the true but unknown value of expected marginal product. The firm will hire the monitor to estimate the value of $E(q_j)$. Employees are hired and assigned shares on the basis of prior information. The prior information is reflected in a provisional estimate of $E(q_j)$ given an information set $\S_j$, defined as $E^*(q_j|\S_j)$.[8] Let us define the firm's total output as Q, the density function over Q as $g(q_1, q_2, \ldots, q_L)$, the periodic rate of interest as r and the quantity of capital as K (the firm has perfect information about the quality of K). The conditional expectation of the present value of firm output given L information sets is defined as $E^*[Q(L, K)]$ and is specified as follows:

$$(1) \quad E^*[Q(L,K)] = \int_{j=1} \cdots \int_{L} \int_{0}^{T} [Qg(q_1, q_2, \ldots, q_L | \S_1, \S_2, \ldots, \S_L)dq_1dq_2 \ldots dq_L e^{-rt}dt]$$

Monitoring is treated as an experiment involving the testing of competing hypotheses about the value of each worker's expected marginal product. When monitoring terminates a conclusion will be drawn that either $E(q_j)$ is above or equal *or* below its provisional estimate $E^*(q_j|\S_j)$. Let us divide these two mutually exclusive outcomes into competing hypotheses H_0 and H_1. Then the hypothesis test conducted on each worker can be specified as follows:

$$(2) \quad \begin{array}{ll} H_0: & E^*(q_j|\S_j) < E(q_j) \quad \forall\, j = 1, \ldots, L \\ H_1: & E^*(q_j|\S_j) \geq E(q_j) \quad \forall\, j = 1, \ldots, L \end{array}$$

For L monitored employees (including the monitor)[9] there will be L hypothesis tests. Assume that the monitor conducts each test through the sequential sampling[10] of one output observation per period from each employee's distribution.

The firm will monitor in order to determine whether the employee's contracted share (reflected in $E^*(q_j|\S_j)$) is equal to the true share $E(q_j)$. If monitoring reveals that $E^*(q_j|\S_j) > E(q_j)$ before T, the firm will terminate the worker and replace him with an alternate from the remaining labor pool perceived to be more productive. The expected returns to monitoring are thus the expected savings from terminating workers found to have been overpaid plus expected gains in productivity from substituting[11] productive for unproductive workers.[12] We do not explicitly incorporate the expected returns to monitoring into our model because doing so would not affect the qualitative results of our model. Instead, we assume that expected returns are already reflected in $E^*[Q(L, K)]$. The expected returns to monitoring are explicitly specified in *Appendix 1.*

In a sequential sampling experiment the number of observations that are required to complete the experiment is a random variable. Define this random variable as t^*, $0 < t^* < T$, where t^* can also be interpreted as the length of time required for monitoring the worker before a conclusion can be drawn as to the true value of $E(q_j)$.

The mean and variance of monitoring time are both related to the variance of the employee's marginal product. From an approximation due to Wald [18] the expected length of monitoring time is proportional to the variance of each employee's marginal product σ^2:

$$(3) \quad E(t^*) = \gamma\sigma^2$$

The intuition behind (3) is clear: as the employee's output variability rises, the likelihood of drawing very high or low observations rises. In order to obtain an accurate measure of mean marginal product, the monitor must on average take more observations. Let $\sigma^2_{t^*}$ be the variance of the number of monitoring periods. From an approximation due to Cox and Roseberry [5] the variance of monitoring time is proportional to the square of the expected length of monitoring time:

$$(4) \quad \sigma^2_{t^*} = \epsilon(\gamma\sigma^2)^2$$

Intuitively, as the variance of marginal product rises, there will be greater uncertainty over the number of observations required to complete monitoring. Details of the monitoring experiment are given in *Appendix 2.*

The monitor's compensation will be the expected present value of sampling costs. See *Appendix 3* for more detail on costs. Since σ^2 is exogenous to both firm and worker, monitoring costs and the monitor's compensation are exogenous.[13] Define c as a fee paid to the monitor for taking one observation of output and $E(M^*)$ and σ_{M^*} as the expected value and standard deviation of the costs of monitoring one worker, respectively. Then the expected value and standard deviation of the monitor's earnings are the following:

$$E(M^*)L = \int_0^{\gamma\sigma^2} cLe^{-rt}dt \tag{5}$$

$$\sigma_{M^*}L = \int_0^{\sqrt{\epsilon\gamma\sigma^2}} cLe^{-rt}dt \tag{6}$$

Let s $(0 < s < 1)$ be the firm's share of output and $(1 - s)/L$ the individual employee's share. Define P_{k^*} as the present value of the cost of holding one unit of capital for T periods (the periodic price of capital is a known constant). Define E(¶) as the expected value of profits and σ(¶)[14] as the standard deviation of profits.[15] Define u^* as $E^*[Q(L, K)]$ for short, U_1 the firm's utility and U_2 the worker's utility. The firm is assumed to maximize the expected present value of utility of profits by choice of s, L and K subject to the constraint that the expected present value of utility for the worker is at least as great as the present value of the utility of opportunity costs. Define these opportunity costs as the present value of a riskless stream of income, W^*. With LaGrange multiplier λ, the firm's maximization problem is given by the following LaGrangian $\emptyset$:

$$\max_{[s,L,K]} \emptyset = E[U_1(E(\P), \sigma(\P))] + \lambda E\left[U_2\left(\frac{1-s}{L}u^*, \frac{1-s}{L}\sigma\right) - U_2(W^*)\right] \tag{7}$$

First order conditions imply the following equilibrium share for the firm[16]:

$$s = \frac{a_1E(M^*) - b_1\sigma_{M^*} + a_2\left(\frac{u^*}{L} - u_L^*\right) + b_2\left(\frac{\sigma}{L} - \sigma_L\right)}{a_2\left(\frac{u^*}{L}\right) + b_2\left(\frac{\sigma}{L}\right)} \tag{8}$$

Let s_1 be the share with positive monitoring costs and s_0 the share with no monitoring costs. Then the share of output paid to the monitor for monitoring services is $(s_1 - s_0)$:

$$(s_1 - s_0) = \frac{[a_1E(M^*) - b_1\sigma_{M^*}]L}{a_2u^* - b_2\sigma} \tag{9}$$

Since the monitor was previously assumed to be an employee participating in production, the monitor's total share of output is $(1 - s)/L + (s_1 - s_0)$ and the difference between the monitor and employee share (the "monitor-employee share differential") is simply $(s_1 - s_0)$.

The monitor-employee share differential is influenced by the distribution of monitoring costs, the distribution of output and tastes. It has a number of interesting properties. First, the differential is independent of employee opportunity costs. If opportunity costs rise, the employee's share rises. Since the monitor is also an employee, his share of output rises as well and both shares will rise by the same amount. But, expected monitoring costs are unchanged, hence the spread between monitor and employee shares will be unaffected. Second, the differential and expected firm output are inversely related (the sign on $\partial(s_1 - s_0)/\partial u^*$ is unambiguously negative). If expected output rises with no change in expected monitoring costs, then expected monitoring costs will be a smaller percentage of expected output than before. Thus even though the expected *dollar* compensation of the monitor for monitoring services does not change, his percentage share of expected firm output received as monitoring fees falls. Third, the differential rises with the number of employees (the sign on $\partial(s_1 - s_0)/\partial L$ is unambiguously positive). If the number of workers rises, the fraction of expected output as expected monitoring costs rises.

Interpretation of the sign on $\partial(s_1 - s_0)/\partial\sigma$ requires a bit more care. The impact of output variability on the differential can be dismantled into a "monitoring costs effect" and a "risk aversion effect":

$$\frac{\partial(s_1 - s_0)}{\partial\sigma} = \frac{a_1[\partial E(M^*)/\partial\sigma] - b_1[\partial\sigma_{M^*}/\partial\sigma]}{a_2(u^*/L) - b_2(\sigma/L)} + \frac{(b_2/L)[a_1E(M^*) - b_1\sigma_{M^*}]}{a_2[(u^*/L - b_2(\sigma/L)]^2} \tag{10}$$

The first term on the right-hand side of (10) is the monitoring costs effect and is unambiguously positive. A rise in output variability increases the expected length of monitoring time, hence the expected present value of monitoring costs and the monitor's share of output for monitoring rises. The second term is the risk aversion effect. If the parties to the contract are risk averse (b_1 and b_2 are negative), then this term will be negative. This is because the monitor's expected utility falls with a rise in risk, holding expected monitoring costs constant. For the case of risk aversion, the sign on (10) will be positive (the monitoring costs effect outweighs the risk aversion effect) if the degree of risk aversion does not lie above some threshold level:

$$\frac{\partial(s_1 - s_0)}{\partial\sigma} \gtreqless 0 \text{ as } -b_2 \lesseqgtr \frac{[a_1E(M^*) - b_1\sigma_{M^*}]\left[a_2\left(\frac{u^*}{L} - b_2\left(\frac{\sigma}{L}\right)\right)\right]}{a_1E(M^*) - b_1\sigma_{M^*}} \tag{11}$$

The sign on (10) is unambiguously positive if both parties are risk neutral or are risk lovers.[17]

THE TEST

In this section a test of the monitor-employee share differential is presented. A major problem with empirical work in this area is the lack of primary data. However, the author was successful in obtaining a small primary data set from the Oregon small vessel (two to seven crew members) commercial fishing industry. The results of the test are to be interpreted with care, given the size of the data set and given the use of some proxies. It is hoped that more data will eventually become available.

Given the obvious difficulty of estimating (9) directly, it was decided to estimate the risk neutrality version $(b_1 = b_2 = 0)$:

$$s_1 - s_0 = \frac{E(M^*)L}{u^*} \tag{12}$$

To capture the effect of variance on the differential we approximate $E(M^*)$ as $\theta\sigma^2$. The regression equation used for estimation was the natural log of (12):

$$\ln(s_1 - s_0) = d_0 + d_1\ln(L) + d_2\ln(\sigma^2) + d_3\ln(u^*) + e \tag{13}$$

$$d_0 > 0$$

$$d_1 = d_2 = 1, \quad d_3 = -1$$

e = classically well-behaved error term

A random sample of 31 vessel owners for twelve different species categories on the Oregon Coast was taken during the Summer of 1985. None of the owners were skippers of their own boats. Vessel owners were asked to give the following information: (1) crew and skipper shares paid; (2) the average number of crew members aboard; (3) trip-by-trip catch data for the season; (4) whether any shares had been altered mid-season and whether there had been any turnover.

For 16 of the owners, information on mid-season turnover and alteration of crew shares was not available. For the remaining 15 owners, eight reported firing crew members mid-season and five reported altering crew shares. Twelve vessels reported harvesting more than one species and six of these vessels reported paying different shares for different species. Thus in general, it appears that vessel owners create species-specific share contracts, since market and production conditions vary across species. On this basis, the thirty-one owners created a total of 46 share contracts (since 31 owners reported harvesting a total of 46 species, many being identical), creating 46 observations on $(s_1 - s_0)$ and L.

Unfortunately, trip-by-trip catch data for each vessel surveyed was not available due to confidentiality and lack of recordkeeping. However, all vessel owners must submit trip-by-trip catch data to the Oregon Department of Fish and Wildlife, but this agency can only release data to the public if the identities of the boat owners are not released. Thus, proxies for each vessel's mean and variance of catch had to be devised.[18] First, the vessels surveyed were classified according to species-vessel length categories (in ten foot intervals). For example, a 46 foot bottomfish trawler constituted an observation in the 40–49 foot bottomfish trawler category. For each category containing observations from the owner survey, a random sample averaging 15 vessels in the Oregon Fish and Wildlife Department data bank was taken and the average mean catch and average variance of catch were calculated. Average mean catch was used as a proxy for u^* and average variance of catch was used as a proxy for σ^2 for each boat.

Regression equation (13) was estimated using ordinary least squares. The regression utilized 42 of the 46 survey observations, or 29 of the 31 vessel owners.[19] Table 1 lists the observations used in the regression. The following estimate of (13) was obtained:

$$\ln(s_1 - s_0) = \underset{(3.21)}{1.88} + \underset{(1.77)}{.62}\ln(L) + \underset{(1.89)}{.10}\ln(\sigma^2) - \underset{(-3.23)}{.28}\ln(u^*) \tag{14}$$

$$R^2 = .25 \qquad F(3/42) = 4.27$$

The numbers in parentheses under each coefficient are the t statistics. All signs on the coefficients are in the hypothesized directions and significant at the five percent level. The equation is significant at the five percent level. Strong multicollinearity between $\ln(u^*)$ and $\ln(\sigma^2)$ was present, but this is mostly due to the fact that identical pairs of observations for u^* and σ^2 were used. For example, because a large number of observations from the bottom trawl 70–79 foot category were used, the proxies for $\ln(u^*)$ and $\ln(\sigma^2)$ from that category were used a large number of times. This repeated used of the same pairs of observations creates a natural correlation between the observations. No evidence of heteroskedasticity was found.

CONCLUSIONS

This paper has presented a theory and preliminary test of monitoring of employees in share contracts when there is no moral hazard. The paper began with a survey of some stylized facts from the small vessel commercial fishing industry relating to supervision of crew members by skippers, catch variability and pay differentials between skippers and crew members. The paper was primarily motivated by the general observation that skippers are not policemen, but samplers of output. In an attempt to explain these stylized facts, the paper departed from the customary principal-agent approach to monitoring. The usual explanation of supervisory-employee pay differentials is that supervisors are paid a premium reflecting net returns to

TABLE 1
Regression Observations

#	Boat #	$\ln(s_1 - s_0)$	$\ln(L)$	$\ln(u^*)$	$\ln(\sigma^2)$
1	1	1.61	1.1	10.2	19.45
2	1	1.61	1.1	10.06	19.17
3	2	1.61	1.1	11.11	16.24
4	2	1.61	1.1	10.06	19.17
5	3	1.61	1.1	10.06	19.17
6	3	1.61	1.1	11.11	16.24
7	4	2.40	1.1	8	15.67
8	5	2.71	1.1	6.8	14.25
9	5	2.48	.69	8.09	16.27
10	5	2.71	1.1	5.92	12.18
11	6	2.48	1.1	6.8	14.25
12	6	2.56	1.1	9.15	17.84
13	7	2.08	1.1	8.09	16.27
14	7	2.08	1.1	5.92	12.18
15	8	2.30	1.1	9.07	17.67
16	10	2.35	1.1	8.09	16.27
17	10	2.08	1.1	10.06	19.17
18	11	2.08	1.39	10.06	19.17
19	12	2.08	1.1	10.06	19.17
20	12	2.64	1.61	8.1	18.81
21	13	1.79	1.1	10.06	19.17
22	14	2.83	1.79	8.41	14.85
23	15	1.61	.69	6.32	14.8
24	15	1.61	.69	8.43	14.92
25	16	1.61	1.1	10.06	19.17
26	17	.69	1.39	7.11	14.51
27	17	.69	1.39	11.11	16.24
28	18	1.1	.69	9.43	17.23
29	18	1.1	.69	6.01	12.19
30	19	1.61	1.1	8.09	12.67
31	20	1.1	1.1	8.22	13.91
32	20	1.1	1.1	9.07	17.67
33	21	2.3	1.1	9.07	17.67
34	23	1.50	1.1	10.06	19.17
35	24	2.12	1.39	10.06	19.17
36	25	2.08	1.39	10.06	19.17
37	26	1.39	1.39	10.06	19.17
38	27	1.79	1.1	10.06	19.17
39	28	1.50	1.1	10.06	19.17
40	29	1.39	1.1	10.13	19.48
41	30	1.79	1.1	9.74	18.42
42	31	2.53	.69	5.19	12.65

Source: Oregon Department of Fish and Wildlife—Catch Data. Personal Interviews—Non-Catch Data. Nicholas Furman—Non-Catch Data. Hans Radtke—Non-Catch Data. Elma Marxen—Non-Catch Data. Albert Gann—Non-Catch Data.

policing of workers. The symmetric information model has suggested that premiums can also reflect the costs of measuring employee output. Our empirical results offer strong support for the hypothesis that differences in skipper-crew share differentials across boats and species reflect differences in the costs of learning about the mean productivities of crew members.

The next step in the research is the development of a joint policing-learning theory and test. In the symmetric information model, output variability and monitoring costs are exogenous and firms were depicted as adapting to these costs through the allocation of resources to monitoring. However, in an asymmetric information model it is entirely possible that an employee's output distribution is endogenous to the monitoring process. In other words, the incentive structure and intensity of monitoring could influence output variability, as well as the average level of performance. A potentially fruitful approach to developing a joint policing-learning model is studying how firms monitor to minimize variance and maximize average performance, in addition to learning about productivity. Issues such as monitoring the monitor, the construction of a compensation scheme to suitably motivate the monitor and the choice of contracts given relative policing and learning costs, would all become important. It will be interesting to see the development of a monitoring model based on the integration of the principal-agent and output measurement approaches to monitoring.

FOOTNOTES

1\. Based on interviews with thirty-one small commercial fishing vessel owners on the Oregon coast during the Summer of 1985.

2\. If equal shares were observed this could well be consistent with no sorting: the vessel owner might be dividing total value of catch by number of crew members. Vessel owners interviewed said that they did not engage in this practice.

3\. This is evident in the following quote from their paper: "We use the term 'monitor' to connote several activities in addition to its disciplinary connotation. It connotes measuring output performance, apportioning rewards, observing the behavior of inputs as means of detecting or estimating their marginal productivities and giving assignments or instructions in what to do and how to do it." (page 782)

4\. It is commonly recognized in the contract literature (see Cheung [4], Eswaran and Kotwal [7, 8], Lazear [9], Lucas [11] and Pencavel [13]) that the share contract is an imperfect (relative to fixed rent contracts) "self policing" contract in that workers will have the incentive to maximize quantity produced and firms may actually choose share contracts over time contracts because enforcement costs are lower. However, in team production shirking on contracted shares can certainly still occur.

5\. This assumption is made for expositional simplicity. The same qualitative results of the subsequent model hold if we assume other distributional forms.

6\. This is a reasonable assumption because employees of the same firm or industry are probably exposed to the same exogenous factors that cause output variability. For example, in berry picking pickers may differ in their experience levels, causing differences in mean productivities. But, all workers may be exposed to variabilities in weather and market conditions, causing uniform output variability across workers.

7\. The results of the subsequent model do not hinge on the monitor having a comparative advantage in monitoring. In this case, the firm arbitrarily contracts out to a third party for monitoring services. This assumption bypasses explanation of the processes by which the firm and monitor negotiate the monitor's compensation. We are implicitly assuming that the firm monitors the monitor because the firm will pay the monitor what it would cost the firm to do the monitoring.

8\. The information set may contain data on experience, skills, education, performance with other firms, etc.

9\. The monitor estimates his own expected marginal product.

10\. The theory of sequential sampling is due originally to Wald [18]. Arrow, et al. [2] and DeGroot [6] have applied Wald's theory to other types of decision problems. The hypothesis test specified is an application of Wald's "Sequential Probability Ratio Test" that the mean of a normal distribution with known variance exceeds a predetermined value. In this application the unknown parameter is the expected value of marginal product and the predetermined value is the provisional estimate of expected marginal product. While Wald's test procedures were originally intended for applications to product quality control and acceptance inspection, his theoretical framework yields insights into the employee monitoring problem. In non-sequential sampling or "fixed sample size" experiments, the number of observations taken is determined before the experiment begins. Sequential decision procedures have the distinct advantage that on average, less observations need to be taken compared to non-sequential decision procedures, for the same parent distribution. Specifically, the expected sample size for a sequential procedure is always less than the optimal predetermined sample size of a non-sequential procedure. It follows that expected sampling costs are on average lower for sequential procedures and the sequential test will be the optimal test for the firm to use (see DeGroot).

11\. The substitutes would have to be monitored as well and we would need to subtract the expected costs of monitoring them from the expected gains in productivity due to reallocation (see *Appendix 1*).

12\. The expected returns to monitoring will be positive if the expected returns from learning that the worker is overpaid exceeds the expected losses from learning that the worker is underpaid. If shares were flexible upwards and downwards and overpayment and underpayment were equally likely, expected returns to monitoring would be zero. In this model, shares are inflexible downwards. In addition, there is no reason to presume that in a world of symmetric monitoring information, overpayment and underpayment are equally likely. This would be the case if the firm were sampling from the labor pool randomly, i.e. with no prior information about productivity. Intuitively, the firm will wish to minimize the likelihood of overpayment through the use of prior information (screening) at the time of hiring.

13\. This is perfectly consistent with a symmetric information model, where the monitor has no discretionary ability to vary his own productivity. In a principal-agent model, the distribution of monitoring costs would be at least partly endogenous to monitor and firm because the monitor could shirk (misrepresent expected monitoring costs) or display low consistency in performance (raise the variance of monitoring time). The firm would also have control over the distribution because it could design a reward scheme that could suitably motivate the monitor, i.e. reward him for lowering mean and variance of sampling costs.

14\. Note that $E(\P) = su^* - P_{k*}K - E(M^*)L$ and $\sigma(\P) = s\sigma + \sigma_{M*}L$.

15\. For simplicity we define risk in terms of standard deviation rather than variance. Use of variance would lead to the same qualitative results but much more tedious algebra.

16\. The parameters a_1, a_2, b_1 and b_2 are taste parameters. They are defined as follows:

$$a_1 = \frac{\partial E(U_1)}{\partial E(\P)},\ a_2 = \frac{\partial E(U_2)}{\partial\left(\frac{1-s}{L}E(\P)\right)},\ b_1 = \frac{\partial E(U_1)}{\partial \sigma(\P)},\ b_2 = \frac{\partial E(U_2)}{\partial\left(\frac{1-s}{L}\sigma(\P)\right)}$$

17\. Approximately the same condition holds if the firm is risk neutral and the monitor is risk averse.

18\. Strictly speaking, the model requires that we use employee-specific output variability in the test. For obvious reasons, only vessel-specific output variability is available. This poses no problem for while the monitor's role is specifically to ascertain the true value of each workers's expected marginal product, this is equivalent to ascertaining the true value of the team's average performance. It follows that output variance of the team rises with the variance of each worker's output, hence the model's implications are qualitatively identical for the case of vessel-specific output variability.

19\. Four observations of $(s_1 - s_0)$ were excluded because it is not possible to regress observations of ln (0). Attempts were made to remedy this problem by substituting values of $(s_1 - s_0)$ close to zero (such as .05 and .01). Regression results were found to be sensitive to the inclusion of these approximations, with deterioration in statistical significance occurring as $(s_1 - s_0)$ got very close to zero. However, the sensitivity of the results was in large part due to these observations being outliers. We note that almost all of the observations in our data set for $(s_1 - s_0)$ had natural logs in excess of 1 (see Table 1).

REFERENCES

1. A. Alchian and H. Demsetz, "Production, Information Costs and Economic Organization," *American Economic Review*, Dec. 1970, *57*, 777–95.
2. K. Arrow, D. Blackwell and M.A. Girshick, "Bayes and Minimax Solutions of Sequential Decision Problems," *Econometrica*, July–Oct., 1949, *17*, 213–44.
3. S.N.S. Cheung, "Private Property Rights and Sharecropping," *Journal of Political Economy*, Nov.–Dec., 1968, 1107–22.
4. S.N.S. Cheung, "Transaction Costs, Risk Aversion, and the Choice of Contractual Arrangements," *Journal of Law and Economics*, April 1969, *12*, 23–42.
5. P.C. Cox and T. Roseberry, "A Note on the Variance of the Distribution of Sample Number in a Sequential Probability Ratio Test," *Technometrics*, Nov. 1966, *8*, 700–04.
6. M. DeGroot, *Optimal Statistical Decisions*, New York, N.Y.: McGraw-Hill, 1970.
7. M. Eswaran and A. Kotwal, "A Theory of Contractual Structure in Agriculture," *American Economic Review*, June 1985, *75*, 352–67.
8. M. Eswaran and A. Kotwal, "A Theory of Two-Tier Labor Markets in Agrarian Economies," *American Economic Review*, March 1985, *75*, 162–77.
9. Edward P. Lazear, "Salaries and Piece Rates," *Journal of Business*, August 1986, *59*, 405–31.
10. B. Jovanovic, "Job Matching and the Theory of Turnover," *Journal of Political Economy*, Oct. 1979, *87*, 972–90.
11. R.E.B. Lucas, "Sharing, Monitoring and Incentives: Marshallian Misallocation Reassessed," *Journal of Political Economy*, May–June 1979, *87*, 502–21.
12. G.M. MacDonald, "A Market Equilibrium Theory of Job Assignment and Sequential Accumulation of Information," *American Economic Review*, Dec. 1982, *72*, 1038–55.
13. J. Pencavel, "Work Effort, On-the-Job Screening, and Alternative Methods of Remuneration," from: Ronald G. Ehrenberg, ed., *Research in Labor Economics*, Greenwich, Conn., JAI Press, Inc., 1977.
14. J.E. Stiligtz, "Incentives and Risk Sharing in Sharecropping," *Review of Economic Studies*, April 1974, *61*, 219–56.
15. J.E. Stiglitz, "Incentives, Risk and Information: Notes Toward a Theory of Hierarchy," *Bell Journal of Economics*, Autumn, 1975, *6*, 552–79.
16. J.G. Sutinen, "Fishermens' Remuneration Systems and Implications for Fisheries Development," *Scottish Journal of Political Economy*, June 1979, *26*, 147–62.
17. J.G. Sutinen, "The Rational Choice of Share Leasing and Implications for Efficiency," *American Journal of Agricultural Economics*, Nov. 1975, *57*, 613–21.
18. A. Wald, *Sequential Analysis*, New York, N.Y.: John Wiley and Sons, Inc., 1947.

APPENDIX 1
The Expected Returns to Monitoring

The density function over a worker's output is f(q). Define E as E(q) and E* as E*(q | §). Since at $t = 0$, E* is the best estimate of E, the best estimate of the probability of overpayment ($E < E^*$) is the following:

$$\text{(i)} \qquad \int_0^{E^*} f(q)dq$$

Likewise, the best estimate of the probability of underpayment ($E > E^*$) is the following:

$$\text{(ii)} \qquad \int_{E^*}^{\infty} f(q)dq$$

The expected returns to monitoring are the expected present value of savings from terminating overpaid workers plus the expected present value of gains from hiring substitutes in the remaining labor pool. Define y as the best estimate of the mean expected value of output for

remaining members of the labor pool. Then the expected returns to monitoring are the following:

$$\text{(iii)} \qquad \left(\int_{E(t^*)}^{T} \left[\int_0^{E^*} (E^* - E + y)f(q)dq\right] e^{-rt}dt\right)L$$

APPENDIX 2
A Sequential Employee Monitoring Experiment

The monitoring experiment is constructed as follows: (1) the firm decides in advance the maximum amount of risk of drawing an incorrect conclusion it wishes to tolerate. Formally, this will be the maximum acceptable probability of a Type I error (rejecting H_0 in (2) when it is true) and the maximum acceptable probability of a Type II error (failing to reject H_0 when H_1 is true). Define the probability of a Type I error as a, and the probability of a Type II error as b; (2) based on the provisional estimate of expected marginal product $E^*(q_j | §_j)$, the firm selects two numbers $E(q_j)_0$ and $E(q_j)_1$, such that $E(q_j)_0 < E^*(q_j | §_j) < E(q_j)_1$. These numbers guarantee the firm that the probability of a Type I error is a if $E(q_j) < E(q_j)_0$ and the probability of a Type II error is b if $E(q_j) \geq E(q_j)_1$. The wider (narrower) is the interval between $E(q_j)_0$ and $E(q_j)_1$, the smaller (larger) are the probabilities of Type I and II errors. The predetermined error probabilities clearly determine the *width* of the interval, but the value of the provisional estimate $E^*(q_j | §_j)$ determines the numerical values of $E(q_j)_0$ and $E(q_j)_1$; (3) each time the firm takes an observation of output it calculates a "sequential probability ratio"; (4) if the observed sequential probability ratio falls within a predetermined interval the firm continues sampling. If the ratio falls outside of this interval, the firm terminates the monitoring experiment and decides which hypothesis is true.

The sequential sampling experiment presumes that a, b and the two numbers $E(q_j)_0$ and $E(q_j)_1$ are determined exogenously, i.e. the firm does not rely on the monitoring experiment itself to determine these numbers. However, the sequential probability ratio and the acceptance/rejection interval mentioned earlier are determined within the experiment. Let us briefly define these two components to the experiment. Define n as the number of observations taken in the experiment (which may not necessarily be the number of observations required to complete the experiment) and $(q_j)_i$ as the ith observation of $i = 1, \ldots, n$ observations taken of the jth employee. The sequential probability ratio is defined as the ratio of the probability density of the sample $[(q_j)_1, (q_j)_2, \ldots, (q_j)_n]$ if $E(q_j) = E(q_j)_1$ (which is unrelated to the first observation in the sample) to the probability density of the same sample if $E(q_j) = E(q_j)_0$. Define the former density as p_{1n} and the latter density as p_{0n}. Then p_{1n} is merely the probability of drawing the observed sample if the true value of expected marginal product is $E(q_j)_1$ and p_{0n} is the probability of drawing the sample if the true value of expected marginal product is $E(q_j)_0$. The sequential probability ratio is the following:

$$\text{(15)} \qquad \frac{P_{1n}}{P_{0n}} = \frac{e^{-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(q_i - E(q)_1)^2}}{e^{-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(q_i - E(q)_0)^2}}, \text{ where: } \sigma^2 = \text{variance of marginal product.}$$

The probability ratio is computed each time an observation of output is taken. Additional observations are taken as long as the following inequality is satisfied:

$$B < \frac{p_{1n}}{P_{0n}} < A, \tag{16}$$

where $A = (1 - b)/a$ and $B = b/(1 - a)$. Monitoring is terminated with *retention* of the employee if $P_{1n}/P_{0n} > A$ and monitoring is terminated with *termination* of the employee if $P_{1n}/P_{0}n < B$.

APPENDIX 3
The Costs of Monitoring

The purpose of this appendix is to explicitly specify some additional sources of monitoring costs not incorporated into the model in the text. Monitoring costs will be the expected present value of sampling costs for those hired at $t = 0$ plus expected present value of higher shares for underpaid workers plus the expected present value of the costs of monitoring substitutes hired at $E(t^*)$ to replace overpaid workers. Define E^* as $E^*(q|\S)$ and E as $E(q)$. Then expected monitoring costs would be the following:

$$\left(E(M^*) + \int_0^{E^*}\int_{E(t^*)}^{2E(t^*)} ce^{-rt}dtf(q)dq + \int_{E^*}^{\infty} \cdot \left[\int_{E(c^*)}^{T} (E^* - E)e^{-rt}dt + e^{-rE(t^*)}\int_0^{E(t^*)} (E^* - E)e^{-rt}dt\right]f(q)dq\right)L$$