THE ECONOMICS OF EMPLOYEE MONITORING: A SEQUENTIAL MEASUREMENT APPROACH

by

Örn Bodvar Bodvarsson

B.S., Oregon State University, 1979

M.S., Oregon State University, 1981

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
in the Department
of
Economics

SIMON FRASER UNIVERSITY

April 1986

APPROVAL

Name: Orn Bodvarsson

Degree: Ph.D. (Economics)

Title of Thesis: The Economics of Employee Monitoring: A Sequential Measurement Approach

Examining Committee:

Chairman: James W. Dean

John F. Chant
Professor
Senior Supervisor

Stephen T. Easton
Associate Professor

Dennis R. Maki
Professor

Clyde Reed
Associate Professor

Douglas A. Smith
Associate Professor
Department of Economics
Carleton University
External Examiner

Date Approved: April 4, 1986

PARTIAL COPYRIGHT LICENSE

Title of Thesis/Project/Extended Essay

The Economics of Employee Monitoring: A Sequential Measurement Approach

Author:
(signature)

Orn Bodvarsson
(name)

April 14, 1986
(date)

ABSTRACT

This thesis develops and tests a theory of employee monitoring and labor earnings. When the marginal product of employees is stochastic, firms must know the expected value of each employee's marginal product in order to set time rates and shares of output. Otherwise, firms must engage in costly monitoring in order to determine its value.

Two theoretical models and one test of employee monitoring are presented. The first model reformulates an educational screening and signalling model due to Riley. This model embodies an explicit specification of the firm's monitoring problem. Firms are depicted as formulating a hypothesis test of expected marginal product and subsequently engaging in the costly periodic sequential sampling of each employee's marginal product. Firms formulate wage offers based on educational signalling of prospective employees. The equilibrium wage is found to vary inversely with the variance of marginal product.

The second model extends the firm's monitoring problem to share contracting. Firms acquire two types of labor - monitors and employees. Equilibrium conditions governing firm, employee and monitor shares are derived. Employee shares are found to vary inversely with the variance of marginal product. The model is shown to be one of seven special cases of a general model of share contracting with costly monitoring and risk aversion. The equilibrium monitor-employee share differential constitutes an unambiguous test of monitoring in share contracts if firms choose pure share contracts.

The share contracting model is tested through the estimation of the monitor-employee share differential. Estimation is performed using ordinary least squares and primary data obtained from a sample of Oregon commercial fishing vessel owners during the 1984 season. Empirical results offer support for the hypothesis that the share differential is a measure of expected monitoring costs on fishing vessels. The thesis concludes by discussing suggestions for further research.

DEDICATION

To my parents.

ACKNOWLEDGEMENTS

I owe thanks to the following people for helping make this thesis a finished product:

Professor John F. Chant, for serving as my senior supervisor and for his guidance, interest and support;

Professor Dennis Maki, for reading several drafts of the thesis and helping me with the empirical work;

Professors Stephen Easton and Clyde Reed for serving on my committee and their interest:

Professor Peter Coyte, for helping me during the early stages of the thesis;

Dr. Christopher Carter, Nick Furman and Dr. Hans Rodtke for going beyond the call of duty in assisting me in the data collection;

and my freinds Anton Lowenberg, David Hammes, William Gibson, Raymond Brastow, Ben Heijdra and Carl Steppan for their interest in the research, suggestions and words of encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. The Economics of Employee Monitoring: A Survey

Introduction

A firm can be uncertain about an employee's contribution to output either at the time of hiring or after production has started. Activities related to the resolution of uncertainty at the time of hiring are traditionally referred to as "Screening." When uncertainty is only partly resolved by the time production starts, activities related to the resolution of uncertainty when employees are on-the-job are traditionally referred to as "On-the-Job Screening" or "Monitoring." This thesis is about the economics of monitoring. The primary objectives of the thesis are threefold: (1) to propose a rigorous definition of monitoring; (2) to develop a testable theory of monitoring based on the proposed definition; (3) to test the theory empirically.

A survey of the labor economics literature over the past twenty-five years indicates that economists view monitoring of employee productivity as an important phenomenon, but as a problem difficult to conceptualize. There is virtually no model of employee monitoring that proceeds from an explicit choice problem of the firm and/or employee to testable implications compatible with existing data sets. In this chapter, we will survey previous literature on monitoring, assess its strengths and weaknesses and determine what are the most fruitful avenues of research to pursue for obtaining a testable theory of monitoring.

Previous Literature on Monitoring

The term "monitoring" was first used in an economic context by Alchian and Demsetz [1], who described it as the following activity:

> "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." (pg. 782)

In the neoclassical theory of the firm prior to Alchian and Demsetz, firms were assumed to be able to observe employee contribution to output costlessly. In other words, the firm faced no problem in employee incentives since employees would always be exerting maximum effort. Alchian and Demsetz considered the firm to face a "team production" problem, where the only costlessly observable output is the total output of the firm's labor force. If the firm did not expend resources to determine each employee's marginal product, employees would perceive that compensation is invariant to the level of effort and hence, they would have no incentive to exert maximum effort. This problem of employee "shirking" would result in lower output than in a world of costless information. It follows that a firm would contract for the services of a "monitor" (who can be regarded as a supervisor or foreman). The monitor would measure employee output and be entitled to claim at least a fraction of the gains in output from reduced shirking as compensation (Alchian and Demsetz formally referred to the monitor as a "resid-

-ual claimant.")

As indicated in the quotation from Alchian and Demsetz, there are other reasons why firms monitor employees, in addition to enforcing contracts: (1) the firm may clearly wish to know whether an employee's marginal revenue product is below marginal factor cost; (2) if the employee's productivity is dispersed across tasks and the firm's production requires the execution of a wide variety of tasks, then monitoring allows the firm to match each employee with the task for which he/she has a comparative advantage. In general, a firm may monitor an employee for reasons independent of shirking. For example, even if employees are always exerting maximum effort (due perhaps to a utility function over honesty or industry), a firm may require information about productivity in order to hire, reallocate, fire or set appropriate compensation.

Let us distinguish between two dimensions of employee monitoring implicit in Alchian and Demsetz: (1) _Contract Enforcement Monitoring_, the dimension emphasized by Alchian and Demsetz, i.e. monitoring in order to minimize employee shirking; (2) _Output Measurement Monitoring_, monitoring for the sole purpose of learning, which may not be connected with contract enforcement. The firm monitors in this case in order to set compensation, improve the quality of employee-job matches, etc. Clearly, contract enforcement monitoring may depend on output measurement monitoring, but we want to emphasize here that even if employees are exerting maximum effort without supervision, firms will be induced to monitor as long as productivity is not known with certainty. Monitoring literature subsequent to Alchian and Demsetz falls into the contract enforcement category or the output measurement category and we will review both categories of literature.

(i) Contract Enforcement Literature

Papers emphasizing the contract enforcement dimension of monitoring have focussed on the relationship between the costs of enforcement and the choice of contractual arrangements. The principal theme in these papers is that firms will choose a contractual arrangement (specifically an employee compensation scheme) which minimizes the costs of policing employees. Firms can choose between pure time rate contracts, pure piece rate or share contracts, or mixtures of time rate and piece/share contracts. With piece rate pay, a worker is paid a fee per unit produced (cents per pound or dollars per page typed, for example). With a share contract, a worker receives a certain percentage of the value of output produced. There are clearly differences in incentives between time rate and piece/share contracts. For example, a strawberry picker will have a greater incentive to exert himself under a piece rate contract since with a time wage, he could theoretically pick nothing and still earn a wage. Provided that the costs of weighing strawberries do not exceed the gains to productivity from piece rate compensation, the strawberry farmer will always choose a piece rate contract.

Even prior to Alchian and Demsetz, Cheung [6] recognized the connection between the costs of enforcement and choice of contractual arrangements. In addition to risk aversion by at least one contracting party as an explanation of contractual choice, Cheung hypothesized the following:

> "A second reason for the existence of contractual arrangements lies in the different transaction costs that are associated with them. Transaction costs differ because the physical attributes differ, and because different sets of stipulations require varying efforts in enforcement and negotiation." (pp. 24-25)

Cheung observed that for Asian agriculture, share contracting on average involved higher costs of negotiation but lower costs of enforcement than fixed rent or fixed wage contracts.

Stiglitz [29] effectively formalized Cheung's hypothesis by developing a theory of contractual choice where firms can choose between different combinations of piece and time rate pay subject to enforcement and negotiation cost constraints. Stiglitz obtained the result that the piece rate and the supply elasticity of effort (a measure of incentives) are positively related. In a general equilibrium framework, Lucas [14] hypothesized that the incidence of share tenancy will increase with monitoring costs. Pencavel [19] argued that a piece rate contract serves as an "on-the-job screening device" in that it not only suppresses the incentive to shirk but allows for the observation of output (as opposed to input) in order to determine compensation. Workers can signal to employers their productivities via output (in contrast to a time rate contract, where employers draw inferences of output from time spent on the job). If effort is costly to observe, but output is not, then the firm may obtain higher returns through the use of output as an on-the-job screen.

In recent work, Eswaran and Kotwal [9] attempt to develop a general theory of contractual choice in agriculture given alternative regimes of contract enforcement costs. The authors argue that management and supervision are perhaps two of the most important resources in agricultural production, but they are inherently unmarketable due to the high costs of quality evaluation. This is in large part due to the fact that given moral hazard, labor time is an inadequate measure of the quality of labor. Rather, what is important to the farm owner is the combination of labor time and supervision effort applied to reduce shirking. Share contracting has the unique property that the landlord has a comparative advantage in management (overall decision making) while the tenant has a comparative advantage in supervision (because often the tenant's family is the entire labor force on each share plot and the tenant is much better suited to supervise his own family). Given this framework, the authors derive the result that the choice of a contract will depend on the cost of supervision relative to management. When the costs of acquiring the supervisory input are high, share contracting will be the dominant form of contract chosen. When the costs of supervision fall, share contracting will give way to fixed rent contracts and when management costs are high relative to supervision costs, fixed wage contracts will dominate. In a second paper [10], Eswaran and Kotwal use a two period model to advance the hypothesis that the institution of agricultural "permanent" labor (tied and estate labor, farm servants or at-

-tached workers) is created by landlords in order to reduce the costs of monitoring workers performing important tasks.

The general theme of the preceding literature is clearly that piece rate and share contracts have a "built-in" incentive structure that makes monitoring a relatively unimportant activity, i.e. that monitoring can be reduced if firms use piece rate or share contracts instead of time rate contracts. This is because a worker recognizes that his income is tied directly to output and he will have little incentive to shirk on quantity. A piece rate or share contract is thus a self-policing contract that economizes on monitoring costs.

There are important qualifications to the hypothesis that piece rate or share contracts minimize enforcement costs. Even though workers have an incentive to maximize effort in quantity, they may shirk on quality. For example, berry pickers may have natural incentives to maximize poundage, but they may do so at the expense of small berries. In addition, the costs of measuring output (such as weighing berries) may actually exceed the gains due to reduced shirking. The literature has typically brushed these issues aside.

More recent literature on the theory of principal-agent relationships (often referred to as "agency theory") treats the general problem of how firms <u>should</u> devise payment schemes, given costly observation of employee effort. Of many papers in this area, perhaps the most notable is Holmstrom [11].

Unfortunately, the literature on contractual choice and enforcement costs does not explain why certain types of monitoring activities occur in virtually all types of piece rate and share contracts. For example, in commercial fishing crew members are typically supervised by skippers who are charged with hiring and firing crew members, assigning crew members to tasks and acting as intermediaries between the firm and crew. Supervisory personnel abound in nearly all corporations that provide incentive pay plans to employees. In land-based agriculture there are typically "row" and "field" bosses that supervise pickers. If the monitoring occurring in these organizational settings is not oriented to contract enforcement, then what is its purpose (aside from the monitoring of quality, which can be avoided by changing the incentive structure within the firm to penalize workers for shirking on both quantity <u>and</u> quality)?

(ii) Output Measurement Monitoring

Another subset of the monitoring literature, the literature on output measurement monitoring, consists of mostly theoretical work on the general proposition that firms can obtain higher returns to production by acquiring and acting upon information concerning employee performance on-the-job. Two veins of literature can be identified here: (1) The "Screening/Signalling" Literature; (2) The "Information Accumulation" Literature. The Screening/Signalling literature treats monitoring as a peripheral issue, whereas the Information Accumulation literature focusses on it.

Literature on screening and signalling was a response to the pioneering work of Becker [3] and Mincer [15] on the productivity-augmenting effects of education on individual earnings.

Spence [27] proposed the idea that in a world of costly information about employee productivity (in contrast to the costless world of Becker and Mincer), firms may primarily view schooling as a productivity filter or "screen" rather than as a productivity-augmenting device, in their hiring decisions. Under the assumption that productivity and the costs of acquiring education are inversely related (those with higher levels of initial human capital or innate ability face lower time costs of education), prospective employees "signal" their productivities to firms by time spent in school. Firms offer higher wages to the better educated primarily because they know from past experience that the better educated are on average more productive. This contrasts with the world of Becker and Mincer, where firms offer higher wages to the better educated strictly because education contributes to productivity. However, Spence asserted that there need be no productivity-augmenting effect of education, only a stable positive correlation between education and observed productivity. Spence's propositions were developed in more theoretical detail by Riley [22] and Stiglitz [30].

In the Screening/Signalling literature, it was hypothesized that the private returns to education would exceed the social returns. In other words, signalling agents can realize a pure "signalling return", a return to education in excess of its productivity-augmenting effect. The size of these returns was largely arbitrary because economies could gravitate to one of an infinite number of signalling equilibrium wage profiles. Tests of educational screening and signalling were developed shortly after Spence's work by Layard and Psacharoupolos [13], Miller and Volker [17], Riley [23], Taubman and Wales [34] and Wolpin [37]. All these empirical studies except Layard and Psacharoupolos offered support for the hypothesis that education serves primarily as a screen.

The screening/signalling models are characterized by five important structural features: (1) Each employee's productivity is a single number (a non-dispersed distribution over time), which is unknown in the first period (the time of hiring) but known in the second period (production); (2) heterogeneity in the labor pool; (3) asymmetrically informed labor markets with no production of new information; (4) costless monitoring; (5) self-confirming beliefs. These five features caused the monitoring activities of firms to be assumed away. There were two basic reasons for trivializing the monitoring problem. First, with the exception of Riley [23], screening and monitoring were treated as completely independent activities, thus the exclusion of monitoring would not alter any results of the models. Second, since the main interest was to explain the divergence between the private and social returns to education, the focus was on the optimizing behavior of the signalling agent.

Screening and signalling theorists typically solve choice problems of signalling agents, given alternative assumptions regarding ability dispersion and signalling costs, and then close their models by invoking self-confirming beliefs of firms. This assumption of self-confirming beliefs was intro-

-duced originally by Spence and formally referred to as "informational equilibrium." It had three alternative interpretations: (1) firms have perfect point predictions of employee productivity; (2) firms are Bayesian learners and will over time converge to the point where all information about the population distribution of productivities is obtained and from that point on, expectations of productivity will be fully confirmed; (3) at any point in time, competitive firms through simultaneous sampling from the population will on average compensate at levels commensurate with productivity. Informational equilibrium was a very powerful but simple notion. If beliefs about productivity are self-confirming, then the firm's information problem will be a two period one. In the first period, hiring will take place and wage streams are offered on the basis of observed signals. In the second period, productivity will be costlessly and perfectly revealed. The cycle will then repeat itself over and over as new applicants enter the labor pool and old workers leave.

The "Information Accumulation" literature emerged shortly after the literature on screening and signalling. In contrast to the screening and signalling literature, papers in this area advanced the assertion that the firm also produces information about employee productivity and employees are just as uninformed about their productive potential as firms. The labor market was presumed to be symmetrically uninformed, with both sides having incentives to produce information. Central to the Information Accumulation models was the presumption that firm and/or emplo-

-yee engage in some on-the-job learning scheme as a means of drawing inferences about the quality of the employee or the employee/job match.

Jovanovic [12] hypothesized that labor turnover is generated by a dispersed distribution of employee-specific productivity across different tasks and periodic reassignment due to the arrival of new information about worker productivity. MacDonald provided two papers, one focussing on employee accumulation [16] and the other firm accumulation [15] of information. In the first paper, a two-period model of assortative matching and optimal non-sequential information accumulation of firms is used to obtain implications on schooling returns similar to the Screening/Signalling literature. In the second paper, firms sequentially submit to workers an evaluation in the form of a binomial conditional probability statement about the quality of the employee-job match. The worker uses this information to update his inferences about his own skills and to decide whether he wants to stay with the firm. Wages and matches are revised accordingly and equilibrium results are used to explain certain stylized facts including upward sloping age/earnings profiles. A similar but less rigorous model is developed by Viscuzi [35].

Ross, Taubman and Wachter [24] argued that if there is productivity dispersion in the labor pool and signals are used to infer productivity at the time of hiring, upward sloping age/earnings profiles can also be derived from a pure "sorting" model. The authors build a two period model with zero monitoring costs and signal-based wage offers. The average wage per cohort is shown to always be higher in the second period, simply due to the sorting process.

None of the studies in the Information Accumulation literature *explicitly* specify the firm's monitoring technology, the methods by which information will be evaluated or the costs of monitoring. Rather, it is presumed that firms and/or employees are Bayesian decision makers and engage in some type of conditional probability revision scheme over time, with the revision scheme left undefined. In addition, these models do not explore the nature of the relationship(s) between initial wage offers and the actual or expected costs of monitoring. For example, they do not generate any implications that would allow for the *comparison* of interpersonal or interoccupational earnings on the basis of actual or expected monitoring costs. It is commonly recognized that in some occupations the length of time and quantity of resources required to determine the productive potential of employees is considerably greater than in others. Yet, there exist no theoretical or empirical studies which attempt to generate testable hypotheses allowing for the examination of such issues.

Towards a Theory of Compensation and Monitoring Costs

The preceding survey revealed that there is no "theory" of monitoring per se, i.e. there is no theory that proceeds from explicit specification of the firm's monitoring problem and obtains testable implications based on this specification. Much of the recent labor/uncertainty literature has emerged in response to the Screening/Signalling/Human Capital literature, which has primarily been concerned with the returns to education in a world of costly information. Second, the testing of theories of monitoring ultimately requires longitudinal data on such variables as earnings, rank, waiting time to promotion or quantity of supervision. A logical question to ask at this point, therefore, is which avenues of research appear the most promising for pursuing a testable theory of monitoring? We can identify two possible avenues.

The first possible avenue is the construction of a theory that explains interoccupational differences in monitoring costs and a test that allows for the detection of such differences. Although interoccupational differences in monitoring costs are not directly observable in current data sets, they may be inferrable from interpersonal and interoccupational differences in the returns to education. An implicit proposition of the educational screening and signalling literature is that firms use educational screens to economize on monitoring. We would expect firms in high monitoring costs occupations to rely more on screens than firms in low monitoring costs occupations. Can interoccupational differences in monitoring costs and allocation of resources to screening be inferred from interpersonal or interoccupational differences in education received by signalling agents? The answer to this question was attempted by Riley [23], who developed a test of the educational screening hypothesis based on an implicit assumption regarding interoccupadifferences in monitoring costs. His study is discussed at length in the next chapter.

The second possible avenue is the construction of a theory and test of output measurement (non-contract enforcement) monitoring in piece rate or share contracts based on employee-specific output variability. As mentioned in the earlier discussion on the literature dealing with enforcement costs and contractual choice, it was observed that monitoring frequently takes place in share and piece rate contracts. Since it is commonly recognized that piece rate and share contracts are chosen in order to minimize enforcement costs, observed monitoring must take place for other reasons, such as output measurement. Clearly, a requirement of piece rate and share contracts is that output be measured in order to determine compensation. Since firms must take observations of output, such data would have to exist in some form.

It is also commonly observed that an individual employee's output in piece rate or share occupations is variable over time, i.e. each worker's marginal product may vary hour-by-hour, day-by-day, week-by-week for reasons such as weather, health, motivation or market demand variability. Literature subsequent to Cheung's seminal work on the theory of share contracting [5] has treated the issue of output variability in piece rate and share contracts, but strictly in the context of risk aversion and contractual choice. There have been two types of testable implications pertaining to output variability in these studies: (1) the relationship between the variability of returns and the choice of the fraction of compensation based on piece rate pay and the fraction based on time rate pay; (2) the relationship between firm and employee shares and risk. Stiglitz [28] showed that in a mixed contract, if the variance of labor output rises, workers will supply labor only if firms lower the fraction of compensation based on piece rate pay and increase the fraction based on time rate pay, i.e. there is an inverse relationship between the piece rate and risk. Stiglitz also showed in the same paper that the fraction of compensation derived from the piece rate method of payment falls with the degree of risk aversion of the worker (assuming a risk neutral firm).

In a dissertation and two papers by Sutinen [31,32,33], a set of testable implications similar to Stiglitz's was offered. Sutinen asserted, but did not formally prove, that the percentage share of output accruing to risk averse fishermen rises with the variability of income. The rationale for this was that risk averse firms respond to an increase in risk by shifting risk to employees through a higher proportion of compensation based on shares. Since the variability of profits rises with the firm's share of output, the firm will attain a greater degree of immunization from risk through a lower percentage share for itself. This prediction was tested on income data on Japanese fishermen. Approximations of crew shares were regressed on a series of variables including the coefficient of variation of past incomes. Sutinen obtained a positive and insignificant value for the sign on the coefficient of variation.

In a later paper, Sutinen derived the equilibrium share given risk aversion by both firms and workers in a mixed contract setting, with both workers and firms having negative ex-

-ponential utility functions and gamma subjective probability distributions over future output. Surprisingly, the piece rate was found to depend only on the taste parameters of both agents and not on the parameters of their subjective probability distributions. This result was not tested but clearly constitutes a violation of Stiglitz's findings plus Sutinen's casual prediction. Since data on such variables as shares and output variability are virtually non-existent, it is not surprising that Sutinen's work is the only test of a relationship between risk and shares.

An Overview of the Thesis

This thesis pursues the two avenues of research suggested in the previous section. Two models and one test of employee monitoring are presented and the theme throughout the thesis is the explicit specification of the firm's monitoring problem in a world of employee-specific output variability and the resulting implications for labor earnings.

In the next chapter a model of educational screening due to Riley [23] is reformulated to a theory that explains screening *and* monitoring. Riley's model is shown to be an explicit theory of interoccupational differences in expected monitoring costs with implications for interoccupational differences in the returns to education.

In the third chapter a model of share contracting with employee-specific output variability, costly monitoring and risk neutrality is developed. Firms are depicted as hiring two types of labor - monitors and employees. Equilibrium conditions governing shares of firms, monitors and employees are derived and evaluated. The model is shown to be one of seven special cases of a general model of share contracting with costly monitoring and risk aversion. The other six special cases are examined and compared to the risk neutrality/costly monitoring model. The risk neutrality/costly monitoring model is the only case that is testable because the other six cases involve equilibrium conditions too complex for estimation.

In the fourth chapter, one implication of the third chapter's risk neutrality/costly monitoring model is tested on share and output data in the Oregon commercial fishing industry. Empirical results offer support for the hypothesis that the skipper-crew share differential is a measure of expected monitoring costs. In the final chapter, conclusions and suggestions for further research are discussed.

2. Towards an Integrated Theory of Screening, Signalling and Monitoring in Labor Markets: The Riley Educational Screening Test Revisited

Introduction

In a 1979 paper, John Riley [23] presents a test of Spence's [27] Educational Screening Hypothesis, based on an explicit specification of the signalling agent's choice problem, self-confirming beliefs of firms and Current Population Survey data for white males in 113 occupations with at least thirteen years of schooling. Riley hypothesized that if education is used as a screen of employee productivity by employers, then lifetime earnings of signalling agents will on average be lower for occupations where screening is more important. This is implicitly due to higher costs of on-the-job monitoring in those occupations where employers rely more on educational screening. Specifically, the proposition was tested that the slope coefficient of log earnings regressed against time in school for a Mincerian [15] log earnings function will be smaller for occupations where screening is more important ("screened occupations").[1/] Fig. 2.1 illustrates this proposition for hypothetical screened and unscreened occupations. Riley hypothesized that the equilibrium wage profile for the screened occupation will lie below that of the unscreened occupation.

Letting the data determine which occupations are screened and unscreened, Riley reported two subsamples of occupations with statistically significant differences in the slope coef-

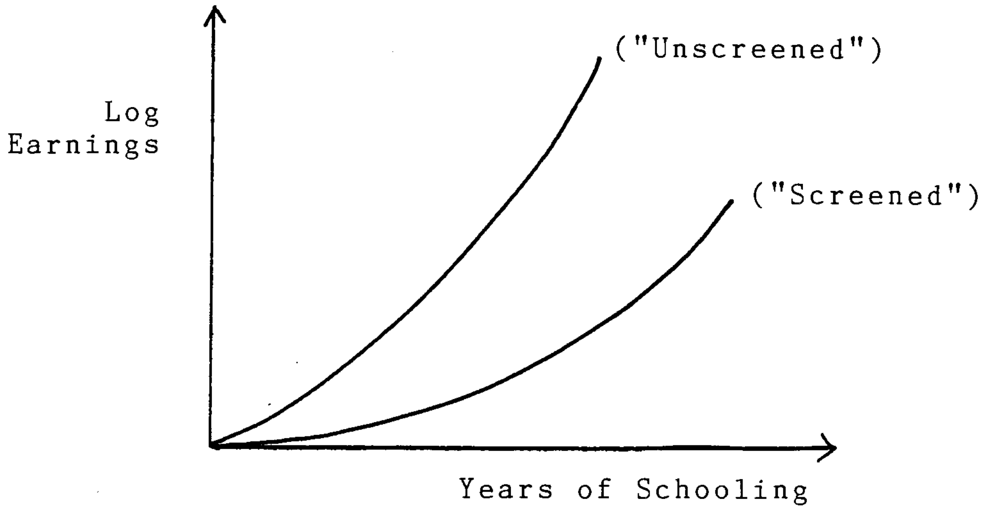

Fig.2.1 The Riley Screening Test.

-ficients of earnings regressed against time in school. The subsample with lower coefficients was determined to be the "screened" subsample and the other subsample was judged to be the "unscreened" subsample. Riley concluded that "...the screenist interpretation of schooling as provider of both additional skills and information indeed offers a more complete explanation of observed behavior than the traditional human capital models" (pp. S250-51).

Riley's theoretical analysis proceeded from three important assumptions: (1) there are interoccupational differences in time and resources required for employers to ascertain the marginal revenue product of an employee; (2) risk averse signalling agents with constant productivity per unit of time, unsure of their market values, choose occupations on the basis of offered wage profiles, educational time costs, perceived initial human capital and their expectations of the length of time a prospective employer will take to identify productivity; (3) firms have self confirming beliefs about productivity and offer wage streams prior to production on the basis of observed educational credentials. With respect to the first assumption, Riley did not explicitly define what he meant by monitoring costs nor did he explicitly specify the firm's monitoring problem.

Perhaps the most important feature of Riley's test is that he did not subdivide the census occupational codes into screened and unscreened categories <u>before</u> performing the estimation. He writes the following on this issue:

> "The catch, of course, is that there is no clearest way of isolating the two sets of agents [screened and unscreened], ex ante. Therefore, instead of using intuition to subdivide the census occupational codes into comparable screened and unscreened categories, it was decided to let the data speak. That is, lifetime earnings functions would be estimated for different occupations and the latter would be divided into a subset with lower earnings functions." (pg. S241)

The purpose of this chapter is to propose a method by which screened occupations can be isolated from unscreened occupations in a test of educational screening. The method is based on the explicit specification of the employee monitoring problem. The chapter begins with a brief review of Riley's theoretical model. Then, an extension of Riley's model is presented through the inclusion of the firm's choice problem and the treatment of the firm's information acquisition scheme as an integrated monitoring/screening problem. The model is used to obtain more empirically specific interpretations of Riley's theory. Specifically, Riley's hypothesis hinges on the variance of employee output. The chapter then discusses data availability and ends by commenting on the implications of the proposed revised version of the Riley test.

The Riley Test: A Review

Riley begins his analysis with the assertion that in some occupations, the costs of evaluating an employee's contribution to the firm may be higher than in other occupations. Thus, we would expect a firm in a high monitoring costs occupation to rely more on educational screening.[2] A five-equation model of signalling and screening is presented:

(1) $y = y(n,z), \quad y_n>0, \quad y_z>0, \quad y_{nz}>0$

(2) $M = M(n,z)\tilde{e}, E(\tilde{e}) = 1, \quad M_n>0, \quad M_z>0$

(3) $L = e^{-ry(n,z)}(W)^{1-\alpha}(M)^{\alpha}, \quad 0<\alpha<1$

(4) $U(L) = \frac{L^{\theta}}{\theta}, \quad \theta >0$

(5) $W[z(n)] = M[n,z(n)]$

where: y = years of schooling;
n = initial human capital;
z = level of educational attainment, e.g. grades, degree;
M = discounted lifetime productivity;
$\tilde{e}$ = random variable;
L = discounted lifetime income;
r = market interest rate;
W = discounted offered wage stream;
U = utility;
θ, α = constants.

Let us focus on equations (3) and (5). In (3), Riley expresses the discounted value of employee lifetime income L as a geometric weighted average of discounted lifetime productivity M and the firm's offered provisional earnings stream W. In those occupations where signalling agents expect firms to take longer in identifying productivity, the parameter α will be lower. If the parameter $\alpha = 1$, true marginal revenue product is determined at the time of hiring and if $\alpha = 0$, true marginal revenue product is determined at the end of the employee's working life. Thus $(1-\alpha)$ is implicitly a measure of the expected or actual fraction of the employee's lifetime with the firm required for monitoring[3/], and low α occupations are those where firms rely more on screening and high α occupations are those where firms rely less on screening. Equation (5) is the Spencian self-confirming beliefs condition, which states that firms will ex post have perfect point predictions of employee productivity.

Employees are assumed to maximize the expected value of (4) by choice of an optimal level of educational attainment z. The first order conditions of the signalling agent combined with the self-confirming beliefs condition (5) are used to show the result that discounted lifetime earnings in the screened sector are lower than in the unscreened sector.

Riley introduces specific forms for ln(M) and ln(y)[4/] in order to simplify the analysis:

(6) $\ln[M(n,z)] = Anz^{v} \quad , \quad A, v > 0$

(7) $\ln[y(n,z)] = \frac{\nu z}{n} \quad , \nu > 0$

Combining (6) and (7), defining $W^* = \ln(W)$ and $M^* = \ln(M)$, Riley expresses the signalling agent's first order condition as the following:

(8) $(1-\alpha)W^*_z + \alpha v Anz^{v-1} = \frac{r\nu}{n}$

Substituting the self-confirming beliefs condition W=M, multi-

-plying (8) through by W*(z), Riley obtains the following:

$$(9)\quad (1-\alpha)W^*W^*_z + \frac{\alpha v(W^*)^2}{z} = r\nu Az^v$$

Riley then assumes that initial human capital n is distributed continuously on some arbitrary interval $[0,n_h]$, which then allows W*[z(0)] = 0. He then obtains the following solution to W*(z):

$$(10)\quad W^*(z) = \frac{2r\nu Az^{(1+v)}}{[(1-\alpha)(1+v)+2\alpha v]Anz^v}$$

Riley then proceeds to express W* in terms of y through the elimination of z and n from (10), since these two are not observable in current data sets. Expressed in terms of y, the solution to the equilibrium wage profile is the following:

$$(11)\quad W^*(y) = \frac{2r}{[(1-\alpha)(1+v)+2\alpha v]}\,(y)$$

From (11), Riley's principal comparative static result is that earnings and the proportional length of time not spent monitoring, α, are positively related:

$$(12)\quad \frac{\partial W^*}{\partial \alpha} > 0$$

Riley's theoretical results depend in large part on the parameter α. But neither is this parameter explicitly defined nor is there any explanation of the factors determining it. Since α is a parameter reflecting proportional length of monitoring time, it appears that Riley's attempt to explain inter-occupational differences in lifetime income, years of schooling held constant, is actually an attempt to explain interoccupational differences in actual or expected monitoring costs. In other words, Riley's educational screening test is actually a test of interoccupational differences in monitoring costs with _implications_ for interoccupational differences in the returns to years of schooling. Since monitoring may be a much more important phenomenon in Riley's analysis, his model needs to be revised to include an explicit specification of the firm's monitoring problem.

A Model of Monitoring with Fixed Wages and Educational Screening

In the following analysis we shift from emphasizing the optimization problem of the signalling agent to emphasizing the problem of the firm (which is customarily not examined in models of screening and signalling). The primary qualitative prediction of the model is due to the explicit specification of the firm's choice problem, but the signalling agent's choice problem is included in the analysis as well.

Consider a risk neutral competitive firm that produces Q units of a commodity per period using labor units L of uncertain quality and capital units K of known homogeneous quality. Production conditions are summarized by a continuously differentiable production function Q(L,K) with diminishing marginal productivities of capital and labor. There are assumed to be t = 1,....,T production periods, a constant product price of unity, no technological change and no growth of firm-specific hu-

-man capital.

The uncertainty over labor quality is the following: the marginal product of each employee varies per period. Factors potentially responsible for variable marginal product include variability in production conditions (changes in the quantity of capital available to each employee, weather or general working conditions) or variability in employee-specific factors such as health or motivation.[5] In addition, the expected value of marginal product for each employee is not known by either the firm or the employee and both sides are equally uninformed about this parameter, i.e. the labor market is symmetrically uninformed.

The distribution of employee-specific marginal revenue product is assumed to be normal.[6] We assume that both employee and firm know the variance of the distribution. The variance of output is the same for all employees, but workers may differ in their mean productivities, i.e. there may be heterogeneity in the labor pool.[7] Intuitively, since *periodic* output varies due to factors typically beyond the control of the employee, the relevant measure of a worker's contribution to the firm is the expected value of marginal product, which measures how a worker performs *on average*. For j=1,...,L workers, define $f(q_j)$ as the density function over the jth worker's marginal product. Defining the periodic interest rate as r, the expected present value of the jth employee's marginal product $E(q_j)$ is the following:

(13) $$E(q_j) = \int_0^T\int q_j f(q_j)\,dq_j\, e^{-rt}\,dt$$

Assume firms pay workers by offering provisional fixed wage streams prior to production. In a competitive market, a firm will attempt to offer a wage stream equal to $E(q_j)$ net of any expected or actual costs of ascertaining its value. If (13) were not known, then in a fixed wage contract, firms will offer wage streams based on some provisional estimate of that parameter. Offered wage streams would reflect this estimate during the time that employers are gathering information about the value of (13).

Production involves drawing one observation per period from each employee's marginal product distribution. Suppose there is a cost of doing so. Since the firm seeks to learn about the true value of (13), it may be profitable to engage in costly periodic sampling from the employee's distribution in order to ascertain the value of (13). Clearly, one observation of marginal product is not sufficient for drawing an accurate conclusion as to the true value of $E(q_j)$. If the distribution is continuous and dispersed, a minimum number of observations in excess of one will be necessary. Thus during the time firms are uncertain about the expected value of marginal product, they are assumed to draw observations of marginal product from each employee's distribution in order to confirm or disconfirm prior estimates of expected marginal product. This estimation process is defined as "monitoring."[8/]

Prior to production, the only information assumed available to the firm on each employee is a provisional predictor or "signal" of expected marginal product. Define the jth employee's signal as y_j, $y_j>0$. The provisional estimate of expected margi-

-nal product is defined as the conditional expectation of marginal product given the signal, $E\#(q_j | y_j)$. Suppose each individual is distinguishable from his/her peers on the basis of the signal's value. Then let us assume that firms believe that the conditional expected value of marginal product is a positive function of the signal and this estimate rises at a declining rate with the signal. The intuition behind this is the following: during previous production periods, firms may have found mean productivities of all previous workers (or cohorts of workers) were correlated with signal levels. While each worker may have a different signal level and hence a different provisional estimate of expected marginal product, we assume that the variance of the individual's marginal product is invariant with respect to the signal.

Suppose we view monitoring as an experiment involving the testing of competing hypotheses about the value of expected marginal product. When monitoring terminates, a conclusion will be drawn that either $E(q_j)$ is above or equal <u>or</u> below its provisional estimate $E\#(q_j | y_j)$. Let us divide these two mutually exclusive outcomes into competing hypotheses H_0 and H_1. Then the monitoring experiment on each employee can be specified as follows:

(14) H_0: $E\#(q_j | y_j) < E(q_j)$
H_1: $E\#(q_j | y_j) \geq E(q_j)$

For L employees, there will be L pairs of hypotheses and L experiments. We assume that the firm tests these hypotheses through the "sequential sampling" of marginal product observa-

-tions.[9] In a sequential sampling experiment, the number of observations required to complete the experiment is a random variable.[10] In addition, observational value boundaries for the acceptance or rejection of H_1 are predetermined. If the number of monitoring observations (the length of monitoring time) is a random variable, then the firm decides after each observation has been taken whether to continue sampling or terminate monitoring and make a decision as to the outcome of the 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 (14) 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 $E\#(q_j | y_j)$, the firm selects two numbers $E(q_j)_0$ and $E(q_j)_1$, such that $E(q_j)_0 < E\#(q_j | y_j) < E(q_j)_1$. 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 <u>width</u> of the interval, but the value of the provisional estimate $E\#(q_j | y_j)$ 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 calcu-

-lates 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 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,..,n observations taken of the jth employee. The sequential probability ratio is defined as the ratio of the probability density of the sample $[(q_j)_1,(q_j)_2,...,(q_j)_n]$ 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 the probability density of drawing the observed sample if the true value of expected marginal product is $E(q_j)_1$ and p_{0n} is the density of drawing the sample if the true value of expected marginal product is $E(q_j)_0$. The sequential probability ratio is the following:

$$(15)\quad \frac{P_{1n}}{P_{0n}} = \frac{e^{-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(q_i-E(q)_1)^2}}{e^{-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(q_i-E(q)_0)^2}}$$, where: σ^2 = 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:

$$(16)\quad B < \frac{P_{1n}}{P_{0n}} < A ,$$

where A = (1-b)/a and B = b/(1-a). Monitoring is terminated with <u>retention</u> of the employee if $P_{1n}/P_{0n} > A$ and monitoring is terminated with <u>termination</u> of the employee if $P_{1n}/P_0n < B$.

With the length of monitoring time uncertain, define t* (random variable), 0<t*<T, as the number of observations (number of monitoring periods) that must be taken before the experiment can be terminated. From an approximation due to Wald [36], the expected number of monitoring periods is proportional to the variance of each employee's marginal product, σ^2:[11]

$$(17)\quad E(t^*) = \gamma\sigma^2,\ \gamma > 0$$

The expected sample size is discussed in more detail in the <u>Appendix</u>. The constant γ implicitly reflects the "efficiency" of the experiment in that a lower (higher) value implies a shorter (longer) experiment on average. The intuition behind (17) is clear: There are two factors which influence the expected length of the experiment. The first is the desired precision of the experiment (reflected in γ). The second is the varia-

-bility of each employee's output. If the firm seeks a high level of accuracy in monitoring, either through requiring low values for a and b or a wide interval between $E(q_j)_1$ and $E(q_j)_0$, expected monitoring time will be higher, than if less accuracy is desired. In those occupations where employee output variability is high over time, the probability of drawing very high or low observations of output rises. In order to obtain an accurate estimate of the expected value of marginal product, the firm must <u>on average</u> take more observations. Conversely, for occupations where employee output is less variable over time, firms will on average spend less time monitoring employees since fewer observations will be required in order to complete the experiment.

A brief numerical example of a hypothetical sequential monitoring experiment is the following. Suppose $a = .05$, $E(q_j)_1 = 175$, $b = .05$, $E(q_j)_0 = 135$ and the variance of marginal product equals 625. Then $A = 19$ and $B = .05$. Suppose the firm takes three consecutive observations of output, 115,185 and 105. Is it possible for the firm to terminate the experiment with one, two or all three observations? Condition (16) would be used to determine this. Inserting the appropriate values into (16), the firm would continue sampling if the observed sequential probability ratio falls between .05 and 19. For the first observation, the ratio is .07, the second observation 15.33 and the third observation .03. The first and second observations would not be enough information for the experiment to terminate but the third observation would yield conclusive evidence. The firm would therefore stop monitoring after the third observation and terminate the employee, because a conclusion would be drawn that expected marginal product lies below its provisional estimate.

If the monitoring experiment terminates prior to the Tth period, then the net returns to monitoring will be equal to the value of output gains less sampling costs. In fixed wage contracts, there are two sources of output gains: (1) the termination of low quality workers and the substitution of high quality workers from the remaining labor pool;[12/] (2) if the productivity of each worker varies across tasks, the reallocation of workers from less productive to more productive matches. In contracts where firms may alter wages, another source of monitoring returns is the reduction of wages for those workers discovered to have been overpaid. We do not explicitly specify the magnitude of monitoring returns because they do not alter the fundamental implications of the subsequent analysis. In effect, we will assume that expectations of monitoring returns are already reflected in the provisional estimate of expected marginal product $E\#(q_j|y_j)$.

We now define monitoring costs. Define c as the constant cost of taking one observation of employee output. Then the expected present value of the costs of monitoring one worker E(M*) are the following:

$$(18)\quad E(M^*) = \int_0^{E(\tau^*)} ce^{-rt}dt = \int_0^{\gamma\sigma^2} ce^{-rt}dt$$

We note that expected monitoring costs rise at a rising rate with variance of output.

Now define W as the discounted value of lifetime wages offered to each employee and define $c^* = \int_0^T ce^{-rt}dt$. Recall Riley's use of the geometric weighted average in expressing an employee's lifetime income, $L = W^{1-\alpha}M^{\alpha}$. In Riley's model, this expression described the signalling agent's formulation of his own income. In this analysis, we allow this function to represent the <u>firm's</u> perception of the value of wages paid out to each employee. The signalling agent's choice problem will reflect some formulation of income by the agent, but a simplified version of this will be presented a bit later in our analysis.

We note that since Riley's parameter α reflects the relative length of monitoring time, the parameter is reexpressed as the following: for T periods of employment $E(t^*)/T$ percent of the employee's life with the firm consists of expected monitoring time and $[T-E(t^*)]/T$ does not. Thus $\alpha = [T-E(t^*)]/T$ and $1-\alpha = E(t^*)/T$. Following Riley's use of the geometric weighted average, let us express the expected present value of the total costs of maintaining each employee for T periods § as the following:[13]

$$(19)\quad \S = (W+c^*)^{\frac{E(t^*)}{T}} (W)^{\frac{T-E(t^*)}{T}}$$

Define $h = \gamma/T$ and $(W+c^*) = \varnothing W$, $\varnothing > 1$.[14] Then for L employees monitored $E(t^*)$ periods apiece the expected present value of total labor costs § may be reexpressed as the following:

$$(20)\quad \S = (\varnothing^{h\sigma^2} W)L$$

Allow total firm output Q to be a function of individual employee output, i.e. $Q=Q(q_j, q_{j+1}, q_{j+2}, \ldots, q_L)$. Since each q_j

is a random variable, Q is a random variable. In particular, Q is an L-dimensional random variable with density function defined as $g(q_j, q_{j+1}, \ldots, q_L)$. Strictly speaking, since the firm's total output is a function of a vector of employee-specific output, the firm will make two labor decisions: (1) The total quantity of labor time <u>per worker</u> to acquire; (2) The total number of workers to hire. This is because we are implicitly assigning each employee his own production function $q_j(l_j, k_j)$, where l_j is the total input of the jth worker and k_j is the quantity of capital stock employed. For present purposes, we will ignore the choice of employee-specific labor time and treat only the choice of the number of workers.[15/] Therefore we treat the firm's production function simply as Q(L,K). The conditional expectation of the present value of total firm output given L signals is defined as the following:

$$(21)\quad E\#(Q / y_1, y_2, \ldots, y_L) = \int \cdots \int_{L} \int_{0}^{T} [\; Qg(q_1, \ldots, q_L / y_1, \ldots y_L)\, dq_1 \ldots dq_L\, e^{-rt} dt]$$

Define $P_k{}^*$ as the discounted value of the cost of one unit of capital for T periods and θ as the expected present value of profits over T periods. By choice of L workers and K units of capital, the firm is assumed to maximize the expected present value of profits:

$$(22)\quad \underset{[L,K]}{\text{Max}}\ \theta = E\#[Q(L,K) / y_1, y_2 \ldots, y_L] - (\emptyset^{h\sigma^2} W)L - P_k{}^*K$$

First order conditions imply that workers are hired and capital is acquired till the conditional expected present value of marginal product for the last worker hired and last unit of capital acquired just covers expected present value of marginal factor cost:

$$(23)\quad E\#(q_j)_L = \phi^{h\sigma^2} W \qquad \forall\, j = 1,..,L$$

$$E\#(q_j)_K = P_k{}^* \qquad \forall\, j = 1,..,L$$

On the other side of the market, risk neutral employees are assumed to respond to offered wage profiles set on the basis of the signal y, by optimally investing in the signal. To close the model with the most clarity, let us use the simplest possible version of the signal investment problem. The returns to signalling are given by the wage profile W(y). We assume the only relevant costs to the employee are non-time costs of signalling.[16] We make no assumptions regarding the dispersion of initial human capital in the population and the utility functions of signalling agents.[17] Define s as the cost of acquiring one unit of the signal. Then the net returns to signalling R(y,s,W) are wages minus signalling costs:

$$(24)\quad R = W(y) - sy$$

From (24) individuals are assumed to acquire that level of the signal for which the marginal returns to signalling just equal marginal costs:

$$(25)\quad dW/dy = s$$

With a negative second derivative of W with respect to the signal, a maximum is guaranteed.[18]

The next step is to derive the equilibrium wage profile. To obtain an equilibrium relation that will yield meaningful comparative static results, we must specify functional forms for the firm's conditional expectation of each employee's marginal product. Adopting a simpler version of a form used by Ri-

-ley, allow $E\#(Q|y) = Ay^v$, $A, v > 0$, $0<v<1$. Since the firm and employee were assumed earlier to have identical estimates of the employee's expected marginal product, the employee estimates that his wage stream will equal $Ay^v - E(M^*)$. Thus, the signalling agent's choice problem may be reexpressed as the following:

(26) $$\underset{(y)}{\text{Max}}\ R(W,y,s) = Ay^v - E(M^*) - sy$$

The first order condition implies the following:

(27) $$Ay^v = \frac{sy}{v}$$

From (23) the firm's profit maximization condition is the following:

(28) $$W = \frac{Ay^v}{\phi^{h\sigma^2}}$$

Substituting the expression for Ay^v in (27) into (28), we obtain the equilibrium wage profile:

(29) $$W = \left(\frac{s}{v\,\phi^{h\sigma^2}}\right)y$$

Allow y to be years of schooling. Then if y is constant, we obtain the comparative static result that wages and the variance of marginal product are inversely related:

(30) $$\frac{\partial W}{\partial \sigma^2} < 0$$

The intuition behind this result is clear: since expected monitoring costs are proportional to the variance of marginal product, a higher variance of marginal product raises expected production costs and hence leads to lower wages. Specifically, if the variance of marginal product rises, firms expect the number of monitoring periods required to ascertain productive potential of employees to rise. The higher expected number of monitoring periods raises expected monitoring costs, expected production costs and results in lower wages.

Using Riley's definitions of "screened" and "unscreened" occupations, we may now restate the educational screening hypothesis given our new formulation of Riley's model: holding years of schooling constant, lower discounted wages are offered to employees in occupations where employee output variability is perceived to be higher. Fig 2.2 illustrates this proposition for two occupations A and B, where $\sigma_A^2 > \sigma_B^2$. Equation (29) implies that the equilibrium wage profile for A (the "screened" occupation) lies below that of B (the "unscreened" occupation).

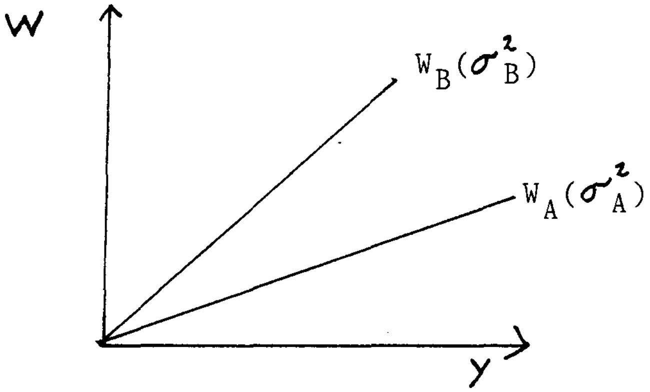

Fig 2.2 Wages and Output Variability

Fig.2.2 is generally equivalent to Fig.2.1 in that the difference between the two profiles illustrated reflects expected monitoring costs. Riley distinguishes between the two wage profiles on the basis of some unexplained parameter α. In this analysis we have given more empirical content to α by deriving the result that α is principally determined by the variance of marginal product.

Other comparative static results from (29) imply the fol-

-lowing predictions: (1) higher wages are offered to those with greater levels of schooling; (2) the rate of return to education is constant; (3) wages and non-time educational costs are positively related; (4) wages and periodic monitoring fees are inversely related.

Conclusions

The relationship between wages, schooling and employee output variability implied by the equilibrium wage profile derived in the previous section challenges Riley's assertion that "...there is no clearest way of isolating the two sets of agents ex ante" in a test of the educational screening hypothesis. If data on employee output variability were available over a cross section of occupations similar to the cross section used by Riley in his empirical work, then those occupations with high output variability are "screened" occupations and those with low output variability are "unscreened" occupations. On face value, Riley's test employs the notion that the two sets of occupations can be distinguished from one another on the basis of some undefined parameter α which supposedly is an all-encompassing measure of relative monitoring time and costs. However, these costs are nowhere to be found in Riley's model, as the self-confirming beliefs condition (W=M) presumes that the firm faces no other costs of labor acquisition other than the going market wage. But since as Riley presumes, "..educational screening, if employed at all, should be used more extensively in occupations with high costs of direct evaluation," his theoretical model requires the explicit specification of the firm's monitor-

-ing problem. The preceding analysis demonstrated how explicit specification of the firm's costs and technology of monitoring injects considerably more empirical content and specificity into the Riley model and test.

There are two challenges to operationalizing this new view of the Riley test: (1) obtaining data on employee-specific output variability for a cross section of occupations; (2) determining whether a modification of the preceding analysis to reflect risk aversion would alter the predictions of the hypothesis. Unfortunately, data on employee output over time are not available for fixed wage contracts. However, such data are available for share and piece rate contracts. In the next chapter, a version of the major portion of this chapter's model is applied to the problem of monitoring in share contracts and the issues of risk aversion and data availability are discussed at length.

Footnotes to Chapter 2

1. Riley also tested four auxiliary propositions: (1) The log earnings function estimated for screened occupations will fit the data better than for unscreened occupations; (2) A negative correlation between the estimated intercept and the average level of education across occupations; (3) The earnings function for self-employed individuals will lie above that for the privately employed; (4) The ratio of earnings variance after several years on the job and earnings variance with little experience will be higher for screened occupations. Riley reported that all four propositions were confirmed by the data.

2. This proposition connotes a "substitutability" between screening and monitoring, as if the two were joint inputs to the production of information in the firm. If screening and monitoring are substitutes, then on average in occupations where monitoring costs are high, more resources will be devoted to screening and less to monitoring. As the cost of monitoring falls, employers will supposedly substitute resources away from screening to monitoring. Riley did not pursue this avenue of inquiry.

3. There is some uncertainty regarding the directional relationship between lifetime income and required monitoring time in Riley's analysis. Intuitively, we would expect monitoring time and costs to be positively related, hence monitoring time and wages to be inversely related. But this depends on whether the offered wage stream is greater or lesser than discounted productivity. Taking the natural logarithm of L and differentiating with respect to α:

(i) $\dfrac{\partial \ln(L)}{\partial \alpha} = - \ln(W) + \ln(M)$

Clearly, if employees are offered a wage stream more than their true productivity, lifetime income and monitoring time will be positively related:

(ii) $\dfrac{\partial \ln(L)}{\partial \alpha} < 0$ as $\ln(M) < \ln(W)$

This is intuitively appealing as the gap between M and W would be filled by monitoring costs. But Riley makes no guarantee of an inverse relationship since he places no restriction on the sign of $\partial \ln(L)/\partial \alpha$. A possible rationale for a positive sign on this derivative would be the following: If an employee is initially overpaid, then the longer it takes for the firm to discover that he was overpaid, the greater will be the value of "artificial" rents during the monitoring period and hence the greater is income.

4. In the text, Riley expresses $\ln(y) = \gamma z/n$. But, later

he expresses $ry_z = r\surd z/n$. In correspondence with Riley, Riley stated that his intended specification for ln(y) is $\surd z/n$. We note that the solution to W*(y) in (11) is correct if Riley's intended specification is used.

5. The literature has not customarily dealt with employee-specific output variability. The Screening/Signalling literature has presumed dispersion of productivity across individuals in the labor pool, where each individual's output is a number, unknown in the first period and revealed at the beginning of the second period. Pencavel [19] has touched upon individual output variability in a study which examined work effort and piece rate payment systems. He specified an individual's on-the-job production function over output Z as being a function of effort E and hours worked H: Z = Z(H,E). From this production function, output variability can be explained by variability in hours, effort and the covariance between the two. Papers by Jovanovic [12] and Viscuzi [35] have presumed a dispersed distribution of worker productivity across tasks.

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

7. This is a plausible assumption because employees in the same firm, industry or occupation are probably exposed to the same stochastic factors that may cause output variability, at least on average. For example, in construction workers may differ in their experience levels, causing differences in mean productivities. But, all construction workers may be equally exposed to variability in weather and market conditions, causing output variability to be the same across employees.

8. Because we assume informational symmetry in the labor market, workers will be unable to provide the firm with any information other than that used in the firm's provisional estimate of expected marginal product. In addition, firms will have no incentive to engage in moral hazard as they have no informational advantage over employees. Thus, there is no contract enforcement dimension to monitoring in this discussion.

9. The theory of sequential sampling is due originally to Wald [36]. Arrow, et al.[2] and DeGroot [8] 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 useful insights into the employee monitoring problem.

10. 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 be taken compared to non-sequential procedures, for the same parent distribution and observation costs. Specifically, the <u>expected</u> 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 always lower for sequential procedures. A thorough reference on this issue is DeGroot [8].

11. Wald showed in [36] that this approximation holds only for normal parent distributions and did not pursue an approximation for the variance and higher central moments of the sample size distribution. Actually, little is known about the central moments of the sample size distribution except for one study. Cox and Roseberry [7] presented evidence from Monte Carlo studies that the variance of the sample size distribution with a normal parent distribution is approximately proportional to the square of the average sample number.

12. As an illustration, suppose there are two types of workers in the labor pool, A and B. Allow $E(Q)_A$ and $E(Q)_B$ to be the expected total output of the firm if only A and B are employed, respectively. Assume $E(Q)_A > E(Q)_B$. Suppose the firm happens to hire only B. Then, two strategies can be followed: (1) no monitoring, yielding an expected profit θ of the following:

$$\text{(i)} \quad \theta = \int_0^T E(Q)_B e^{-rt} dt - \int_0^T P_k K e^{-rt} dt - \int_0^T W L e^{-rt} dt \quad ;$$

(2) monitoring, which yields conclusive results at t*, 0<t*<T. In this case, the firm would terminate B workers and seek out A. The expected gain in profits $\Delta\theta$ from doing so would be:

$$\text{(ii)} \quad \Delta\theta = \int_0^{E(t^*)} E(Q)_B e^{-rt} dt + \int_{E(t^*)}^T E(Q)_A e^{-rt} dt - \int_0^T E(Q)_B e^{-rt} dt - E(M^*)$$

where M* is the cost of monitoring. One qualification needs to be made here: if low quality workers were found midstream and the expected productivities of replacements were not known, the firm would need to monitor the new workers. The variable M* in the preceding formulation would reflect the costs of monitoring B workers after hiring and of monitoring workers perceived to be A.

13. Equation (19) is only an appropriate aggregation if the firm expects no turnover between t=0 and T. If the firm expected turnover, then (19) would have to reflect the costs of monitoring replacements hired at E(t*). These costs could be incorporated by assuming that the firm assigns a probability to each employee staying with the firm beyond t* and calculates the costs of monitoring replacements. For expositional simplicity, we do not incorporate expectations of turnover.

14. The value of ϕ thus reflects the periodic monitoring fee.

15. Inclusion of the choice of l_j would effectively add nothing to the comparative static results of interest, other than to yield demand functions for individual workers.

16. This is not to deny that time costs are important. However, the results of the model are not altered in any fundamental way by the exclusion of time costs.

17. The exclusion of a utility function reflects our previous assumption of risk neutrality. If signalling agents are risk averse, then we introduce the notion that agents are affected by output variance in two ways: (1) monitoring costs; (2) aversion towards the variance of output. Since our primary objective is to clarify Riley's analysis and test, we bypass the potentially interesting issue of a dual risk aversion/monitoring costs explanation of compensation and output variability. In addition, because the chief purpose of this model is to explain the relationship between wages and monitoring costs, we are justified in ignoring ability dispersion in the labor pool. If there is ability dispersion, then this will be reflected in a dispersion of signalling costs around the same signal level, i.e. those with greater levels of innate ability will signal at lower relative costs. The key comparative static results of this model do not depend on assumptions regarding the distribution of signalling costs. However, explicit specification of this distribution would be an interesting extension of this model.

18. This condition is implied by an earlier assumption that:

$$d^2E\#(q_j|y_j)/dy^2 < 0.$$

3. Share Contracting, Output Variability and Costly Monitoring

Introduction

In a world of share contracting and stochastic employee-specific output, the firm must know the expected value of each employee's marginal product in order to set optimal shares of output. If that parameter is not known, then the firm may expend resources to determine its value through employee monitoring. Previous literature on share contracting has ignored this reason for monitoring in share contracts.

This chapter is divided into two parts. In the first part, we develop a model of share contracting with stochastic employee-specific output, costly periodic monitoring and risk neutrality. Firms are depicted as acquiring two types of labor - employees and monitors. The monitor's role, in addition to participating in production, is to estimate the expected marginal product of each employee through periodic sequential sampling from each employee's output distribution. Equilibrium conditions governing firm, monitor and employee shares are derived.

In the second part, the refutability of the model is discussed. There are two reasons why the issue of refutability is important: (1) the model is one of seven special cases of a general model of share contracting with <u>risk</u> <u>aversion</u> and monitoring; (2) some of the predictions of the risk neutrality/costly monitoring model can be duplicated by the other six special cases. The question then arises as to whether an unambiguous test of the risk neutrality/costly monitoring model can be obtained. Accordingly, the six additional special cases are exa-

-mined. The risk neutrality/costly monitoring model is found to be the only testable case. The chapter concludes by considering the monitor-employee share differential as a testable implication of the risk neutrality/costly monitoring case.

Share Contracting with Output Variability

We begin our analysis by reviewing the equilibrium conditions of a general model of share contracting with multi-period production and output variability. We assume that firms and employees are risk neutral, there are no transaction costs and the labor market is competitive. Define L as number of employees per unit of time and K as the quantity of capital stock. The firm's production conditions are summarized by a continuously differentiable production function Q(L,K) where Q is periodic output. Both inputs are assumed to display diminishing marginal productivity and are homogeneous in quality.

There are assumed to be t=1,...,T production periods. Each employee's marginal product is assumed to vary across production periods, i.e. for each employee there is a dispersed distribution of marginal product across periods. Since each worker's contribution to total firm output is a random variable, total firm output Q is a random variable. We do not inquire into the nature of the stochastic process governing employee marginal product or Q, as such formalization is not crucial to our subsequent analysis. Rather, let us summarize uncertainty over Q by defining f(Q) as the density function over Q.[1/]

All compensation of labor is assumed to be in the form of a predetermined share of output, set before production. The share remains fixed over all production periods. Let r be the firm's percentage share of output, (1-r) labor's share and (1-r)/L the individual employee's share. With labor homogeneous, employee shares are identical. Define P_k as the constant periodic price of capital and v the constant periodic market interest rate. Assuming a normalized product price of unity throughout, the expected present value of profits ¶ is the following:

(1) $$E(\P) = r\int_0^T\!\!\int Q(L,K)f(Q)dQe^{-vt}dt - \int_0^T (P_k e^{-vt}dt)K$$

Following Cheung [5], the firm is assumed to face the constraint of a competitive labor market that employees must be compensated by at least as much as what they could earn in their next best alternatives. Let these employee opportunity costs be defined as a riskless stream of periodic wage income W. Dispensing with present value notation, we define the following variables:

(2) $$u^* = \int_0^T\!\!\int Qf(Q)dQe^{-vt}dt$$

(3) $$P_k^* = \int_0^T (P_k e^{-vt}dt)K$$

(4) $$W^* = \int_0^T We^{-vt}dt$$

With regard to W*, the firm faces the employee opportunity cost constraint that $(1-r)(u^*)/L \geq W^*$.

The firm's optimization problem is to choose the optimal values of r,L and K. The problem is given by the following LaGrangian Ø where λ is the LaGrange multiplier:

(5) $$\underset{[r,L,K,\lambda]}{\text{Max}}\ \emptyset = ru^* - P_k{}^*K + \lambda\left[\frac{(1-r)}{L}(u^*) - W^*\right]$$

We define first derivatives by subscripts at the bottom of each differentiated variable. First order conditions are the following:

(6) $\emptyset_r = u^*(1 - \frac{\lambda}{L}) = 0$

(7) $\emptyset_L = ru^*_L + \lambda[\frac{(1-r)}{L}][u^*_L - \frac{u^*}{L}] = 0$

(8) $\emptyset_K = ru^*_K - P_k^* + \lambda[\frac{(1-r)}{L}]u^*_k = 0$

(9) $\emptyset_\lambda = [\frac{(1-r)}{L}]u^* - W^* = 0$

From (6), $\lambda = L$. Substituting $\lambda = L$ and solving for $(1-r)/L$ we obtain the first equilibrium condition that the employee share will equal the ratio of expected marginal product to expected total product, i.e. the worker's percentage contribution to the firm's total output:

(10) $[\frac{(1-r)}{L}] = \frac{u^*_L}{u^*}$

From (9), the employee's share must also satisfy the employee's opportunity cost constraint:

(11) $[\frac{(1-r)}{L}] = \frac{W^*}{u^*}$

Equations (7) and (8) imply two additional equilibrium conditions:

(12) $u^*_L = W^*$

(13) $u^*_K = P_k^*$

All four equilibrium conditions simultaneously imply that the firm will maximize the expected present value of profits by acquiring labor and capital to the point where the expected present values of the marginal products of the last units acquired of both inputs just cover their opportunity costs. In addition, labor's share of output will depend on both expected productivity and opportunity costs.

It is clear from these equilibrium conditions that the firm must know the expected marginal product of each employee in order to formulate optimal output shares. But what if this parameter is not known with certainty at the time contracts are negotiated? It is clearly in the interest of the firm to know whether each employee share it sets is too high (perhaps causing losses) or too low (causing the defection of labor). Therefore, the firm will attempt to estimate the expected marginal product of each employee by expending resources to monitor the periodic output of each employee.

A Model of Share Contracting with Costly Monitoring

The objective of this section is to derive and evaluate equilibrium conditions governing firm and employee shares and factor employment when the firm incurs costs to monitor employee productivity. We make the following modifications of the previous section's prototype share contracting model: (1) The output of each employee is a normally distributed random variable with unknown mean and known variance; (2) Both firm and employee are symmetrically uninformed about the employee's mean productivity and both worker and firm form identical provisional estimates of the mean; (3) Workers are allowed to differ according to mean productivity, but not in variance of output; (4)

One employee of the firm is assigned to monitor other employees, but the monitor also participates in production. The monitor is assumed to be uncertain of his own mean productivity in production as a regular employee and he must monitor himself at the firm's expense.

For $j = 1,..,L$ workers (including the monitor), define q_j as the jth employee's periodic output and $h(q_j)$ as its density function. Suppose the true but unknown value of the jth employee's mean productivity is $E(q_j)$. The monitor will then attempt to estimate the value of this parameter. Before production commences, the monitor is assumed to form a provisional estimate of $E(q_j)$, given an information set $\S_j$. The content of this information set might include observations on such attributes as schooling, work experience, references, medical records, criminal and credit records, etc. The provisional estimate is defined as the conditional expectation of productivity, $E^*(q_j | \S_j)$. The density function over total firm output is defined as $g(q_1,q_2,..,q_L)$. The conditional expectation of the present value of total firm output given L information sets is defined as the following:

$$(14)\quad E^*[Q(L,K)] = \int \cdots \int_{L} \int_{0}^{T} [Qg(q_1,q_2,..,q_L | \S_1,..,\S_L) dq_1 .. dq_L e^{-vt} dt]$$

Suppose we view the monitoring process as an experiment involving the testing of competing hypotheses about the value of each employee's expected marginal product. When monitoring terminates, a conclusion will be drawn that either $E(q_j)$ is above or equal <u>or</u> 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 monitoring experiment conducted on each worker can be specified as follows:

$$(15)\quad H_0\colon E^*(q_j | \S_j) < E(q_j) \qquad \forall\ j = 1,..,L$$
$$H_1\colon E^*(q_j | \S_j) \geq E(q_j) \qquad \forall\ j = 1,..,L$$

For L monitored employees (including the monitor), there will be L hypothesis tests. Assume that the monitor conducts these tests through the periodic sequential sampling of output observations from each employee's output distribution. Assume one observation can be taken per period. From the preceding chapter, the number of observations that need to be taken to complete the hypothesis test is a random variable. Define this random variable as t*, $0<t^*<T$, the number of monitoring periods required to obtain conclusive evidence as to the value of $E(q_j)$. Then using the same approximation to E(t*) as in the previous chapter and defining c as a fee paid to the monitor for taking one observation of output, the expected present value of the monitor's compensation E(M*)L is the following:

$$(16)\quad E(M^*)L = \int_0^{E(t^*)} (ce^{-vt}dt)L = \int_0^{\gamma\sigma^2} (ce^{-vt}dt)L$$

Since the number of monitoring trials per employee is a random variable, total compensation to the monitor is a random variable. While the firm decides at the end of every period whether the monitor should continue sampling, the firm cannot treat ex-ante the total quantity of monitoring services as a choice variable. It follows that the expected present value of compensation to the monitor is treated as an exogenously-determined cost.

The next step is to derive three equilibrium shares: (1)

The firm's share of output; (2) Each of L employees' share of output; (3) The monitor's share of output. The firm is assumed to maximize the expected present value of profits by choice of optimal quantities of labor and capital and optimal shares. As in the previous chapter, we will ignore the choice of employee-specific labor time and treat only the choice of the number of workers. Therefore, we reexpress the firm's production function Q as simply Q(L,K) and the conditional expectation of total firm output as E*[Q(L,K)]. Define E*[Q(L,K)] as u* for convenience.

With a competitive labor market, the firm's optimization problem is given by the following LaGrangian:

$$(17)\quad \underset{[r,1,k,\lambda]}{\text{Max}}\ \emptyset = ru^* - E(M^*)L - P_k{}^*K + \lambda\left[\frac{(1-r)}{L}(u^*) - W^*\right]$$

First order conditions are the following:

$$(18)\quad \emptyset_r = u^*\left(1 - \frac{\lambda}{L}\right) = 0$$

$$(19)\quad \emptyset_L = ru^*{}_L - E(M^*) - \lambda\left[\frac{(1-r)}{L^2}\right]u^* + \lambda\left[\frac{(1-r)}{L}\right]u^*{}_L = 0$$

$$(20)\quad \emptyset_K = ru^*{}_K - P_k{}^* + \lambda\left[\frac{(1-r)}{L}\right]u^*{}_k = 0$$

$$(21)\quad \emptyset_\lambda = \left[\frac{(1-r)}{L}\right]u^* - W^* = 0$$

The expressions $u^*{}_L$ and $u^*{}_K$ are the conditional expected values of marginal product of labor and capital, respectively.

From (18) we note that $\lambda = L$. Substituting $\lambda = L$ into (19) and solving for (1-r)/L in both (19) and (20) we obtain the two conditions governing the employee's share of output:

$$(22)\quad \frac{(1-r)}{L} = \frac{W^*}{u^*} = \frac{u^*{}_L - E(M^*)}{u^*}$$

The employee's share of output must simultaneously satisfy the following two conditions: (1) The share will equal the percentage of total conditional expected output contributed by the employee less the percentage of total expected output paid to the monitor for monitoring the employee; (2) The share will equal the ratio of employee-specific opportunity costs to total conditional expected output. Multiplying the individual employee's equilibrium share by the number of employees, we obtain the equilibrium share accruing to the entire labor force:

$$(23)\quad (1-r) = \left[u^*_L - E(M^*)\right]\frac{L}{u^*} = W^*\frac{L}{u^*}$$

Interpreting (23), labor's share of output will simultaneously equal the elasticity of conditional expected output with respect to labor less the ratio of the expected marginal cost of monitoring one employee to the conditional expectation of the average product of labor <u>and</u> the percentage share of total expected output comprising the opportunity costs of labor.

From the equilibrium conditions for the employee's share, we obtain the following comparative static results: (1) The share and opportunity costs are positively related; (2) The share and conditional expected output are inversely related. Since the employee share and expected monitoring costs are inversely related, we obtain three additional results:

$$(24)\quad \frac{\partial\left[\frac{(1-r)}{L}\right]}{\partial c} < 0, \qquad \frac{\partial\left[\frac{(1-r)}{L}\right]}{\partial \sigma^2} < 0, \qquad \frac{\partial^2\left[\frac{(1-r)}{L}\right]}{\partial (\sigma^2)^2} > 0$$

An increase (decrease) in the periodic monitoring fee raises (lowers) the expected present value of monitoring costs, lowering (raising) the employee share. The first and second deri-

-vatives with respect to output variance imply that the share falls (rises) at an increasing (decreasing) rate with output variance. This result is due to the posited technology of monitoring: The greater is the variability of output, then on average a greater number of observations of output must be taken in order to obtain conclusive evidence regarding the value of expected output. The greater the expected number of observations the greater will be expected monitoring costs and hence the lower the employee share.

The optimization problem also implies the following factor employment equilibrium conditions:

(25) $u^*_L = W^* + E(M^*)$

(26) $u^*_K = P_k{}^*$

Labor is acquired to the point where the expected marginal product of the last employee hired just covers the sum of the market wage and the expected marginal costs of monitoring. Capital is acquired to the point where the last unit purchased just covers its marginal cost.

Define S as the monitor's share of output. We made three assumptions about the monitor at the beginning of this section: (1) The monitor also participated in production; (2) The monitor's expected output as an employee in production was uncertain; (3) The monitor would be paid by the firm to evaluate his own output, along with output of his fellow workers. It follows from these assumptions that there will be two components to the monitor's share of output: (1) A share of the output equal to that of a regular employee; (2) A share of output equivalent to expected monitoring costs. Arithmetically, this sum will be the following:

$$(27)\quad S = \frac{(1-r)}{L} + \frac{E(M^*)L}{u^*} = \frac{u^*L - E(M^*)}{u^*} + \frac{E(M^*)L}{u^*} = \frac{W^*}{u^*} + \frac{E(M^*)L}{u^*}$$

From (27), the monitor's share of output clearly rises with opportunity costs and falls with the conditional expected value of output. The larger the periodic monitoring fee and the variance of output, the greater will be the monitor's share of output. In addition, the monitor's share of output rises at a falling rate with output variability ($\partial S/\partial\sigma^2 > 0$, $\partial^2 S/\partial(\sigma^2)^2 < 0$). All these results are again due to the technology of monitoring.

Now let us define Z as the difference between the monitor's and employee's share of output. Clearly, Z will be the following:

$$(28)\quad Z = \frac{\gamma\sigma^2 L}{u^*}$$

The share differential has a number of interesting properties: (1) It is exactly equal to the percentage of output used up by expected monitoring costs; (2) It is independent of employee opportunity costs. The intuition of the second property is the following: If opportunity costs rise, the employee's share rises. Since the monitor is also an employee, his share of output rises as well. Thus (1-r)/L and S rise by the same amount. But, expected monitoring costs are unchanged, thus the spread between the monitor's and employee's share will in no way be affected.

Differentiation of the share differential implies the fol-

-lowing comparative static results: (1) increases in output variability and size of the labor force raise expected monitoring costs, the percentage of expected output expended on monitoring costs and hence the differential; (2) a rise (fall) in expected output reduces (increases) the differential; With (2), if expected output rises with no change in expected monitoring costs, then arithmetically expected monitoring costs will be a smaller percentage of expected output than before. Thus even though the expected <u>dollar</u> compensation of the monitor does not change, his percentage share of expected firm output received as monitoring fees falls.

From (23), the firm's share of output is the following:

(29) $r = 1 - [u^*_L - E(M^*)](L/u^*) = 1-W^*(L/u^*)$

The firm's share of output is positively related to expected output, inversely related to opportunity costs and <u>positively</u> related to expected monitoring costs and the variance of output ($\partial r/\partial\sigma^2 > 0$). As output variability rises (falls), the firm will raise (lower) its share of output to cover the larger (smaller) payment made to the monitor.

<u>Fig. 3.1</u> illustrates the effects of a change in expected monitoring costs on the equilibrium distribution of output in the share contract. The curve labeled $U^*_{L_o}$ is the expected marginal revenue product of labor and the curve labeled $u^*_{L_o} - \gamma\sigma_o^2$ is expected marginal revenue product less expected monitoring costs. The firm will initially hire L* workers. At L*, the firm's share of output is the ratio of total expected output less monitoring and wage costs <u>to</u> total expected output, or

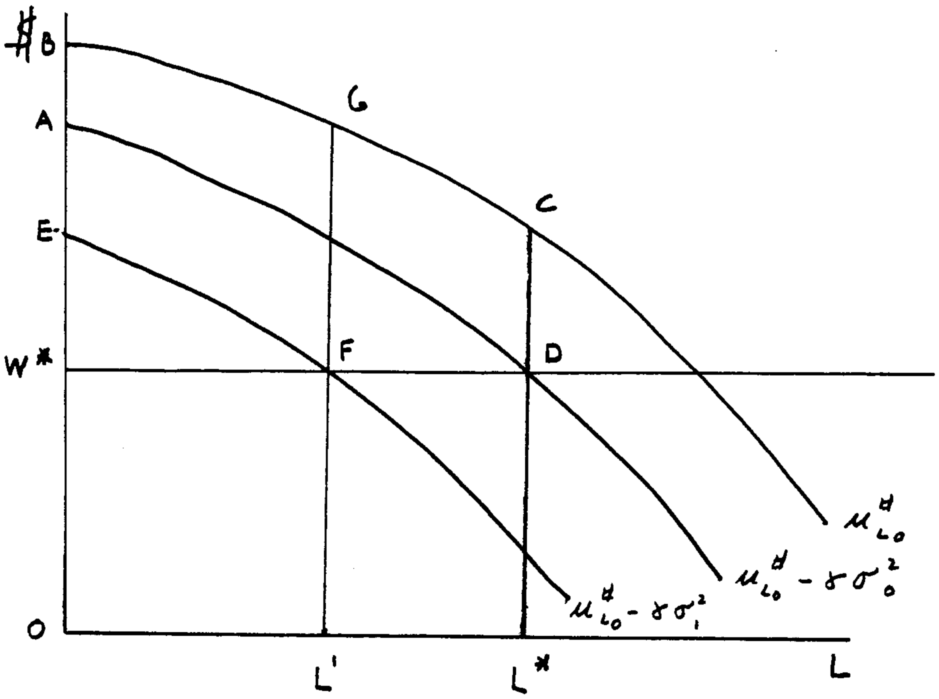

Fig. 3.1 Output Shares and Monitoring Costs

W*AD/OBCL*. Labor's share is OW*DL*/OBCL* and the monitor's share due to monitoring only is ABCD/OBCL*. Now let variance of employee marginal product rise to σ_1^2 from σ_0^2. The firm, facing higher expected marginal costs, trims its labor force to L'. Even though dollar compensation to each employee is unchanged (FL'=DL*), the employee's share of output is smaller since the equilibrium condition for the labor share OW*FL'/OBGL' is less than OW*DL*/OBCL*.

A General Model of Share Contracting with Risk Aversion and Costly Monitoring

In the previous section we derived and evaluated three equilibrium conditions implied by a theory of share contracting with risk neutrality and costly monitoring. Output shares were shown to vary with output dispersion because expected monitor-

-ing costs are partly determined by output variability. The share contracting literature has focussed on another explanation of shares and output variability - risk aversion. In the first chapter of this thesis, we surveyed some previous theoretical studies that generated implications for the relationship between shares and output variability. It was clear from this survey that not only did these models not examine the implications of costly monitoring, but they were unable to generate a <u>general</u> comparative static result on shares and output variability. Rather, conflicting results were derived due to the fact that each study relied on restrictive assumptions over tastes and beliefs of agents.

One result of the studies of Stiglitz [28,29] and Sutinen [31,32,33] was that in some cases, employee (firm) shares could be inversely (positively) related to output variability. The costly monitoring model of the previous section generated the same prediction. Suppose we were to test this prediction on share and output variability data and a statistically significant and inverse correlation was observed. Then is there any a-priori way of distinguishing between a test of shares and output variability based on a model of risk neutrality and costly monitoring, and a test based on some other special case such as risk aversion?

The first step in determining the actual refutability of the previous section's model is a <u>critical</u> and <u>general</u> appraisal of risk aversion <u>and</u> costly monitoring in share contracts. From the risk aversion literature surveyed, we appear to lack a common ground for comparing the predictions of a "pure" risk aversion model and the previous section's model, not to mention the restrictive models of Stiglitz and Sutinen.

In this section we develop a general mean-variance model of share contracting that includes both risk aversion and costly monitoring. The risk neutrality/costly monitoring model of the previous section is shown to be one of seven special cases of this general model. The implications of the other special cases are compared to the implications of the previous section's model in order to determine the degree of overlap between the special cases in qualitative predictions, and whether the special cases can be distinguished from one another on empirical grounds.

To begin our analysis define U_1 as the firm's utility and U_2 as the employee's utility. Allow the expected utility of profits function for the firm to be defined over the expected present value of profits E(¶) and the standard deviation[3/] of profits σ(¶). Since the cost of monitoring M* is a random variable, one source of profit uncertainty is uncertainty over the realized value of M* (due to uncertainty over the number of monitoring periods t*). We must therefore include the variability of monitoring costs (defined as the standard deviation of M*) in the definition of the standard deviation of profits. Define σ_{M*} as the standard deviation of the cost of monitoring one employee. Clearly the variance of M* (σ^2_{M*}) is in the general case the following:

(30) $$\sigma^2_{M*} = E\ [\int_0^{t*} ce^{-vt}dt - \int_0^{E(t*)} ce^{-vt}dt]^2$$

Define σ^2_{t*} as the variance of the number of monitoring periods. From an approximation due to Cox and Roseberry [7], the variance of the number of monitoring periods is proportional to the square of the expected number of monitoring periods:

(31) $\sigma^2_{t*} = \varepsilon\,(\gamma\sigma^2)^2, \quad \varepsilon > 0$

It follows that the standard deviation of monitoring costs is the following:

(32) $\sigma_{M*} = c \int_0^{\sqrt{\varepsilon}\,\gamma\sigma^2} e^{-vt}\,dt$

Then the expectation and standard deviation of the present value of profits are the following:

(33) $E(\P) = ru^* - P_{k*}K - E(M^*)L$

(34) $\sigma(\P) = r\sigma + \sigma_{M*}L$

Allow the expected utility of income function for the employee to be defined over the expected value of income and the standard deviation of income. These two parameters are defined as $[(1-r)U^*]/L$ and $[(1-r)\sigma]/L.$, respectively. For expositional simplicity, we assume all higher central moments of the subjective probability distributions for both agents are nonexistent. Finally, define $U_2(W^*)$ as the utility of the present value of opportunity costs.

The firm is assumed to maximize the expected present value of utility subject to the constraint that the expected present value of utility for the employee is at least as large as the present value of the utility of opportunity costs. The firm's maximization problem is defined by the following LaGrangian:

(35) $\underset{[r,L,K,\lambda]}{\text{Max}}\ \phi = E[U_1(E(\P), \sigma(\P))] + \lambda E[U_2(\frac{1-r}{L}u^*\ ,\ \frac{1-r}{L}\sigma) - U_2(W^*)]$

We also impose the following abbreviated definitions:

(36) $$\frac{\partial E(U_1)}{\partial E(\P)} = a_1, \quad \frac{\partial E(U_1)}{\partial \sigma(\P)} = b_1, \quad \frac{\partial E(U_2)}{\partial [\frac{(1-r)}{L}]u^*} = a_2, \quad \frac{\partial E(U_2)}{\partial [\frac{(1-r)}{L}]\sigma} = b_2$$

The preceding parameters are the marginal expected utilities of expected value and risk for firm and employee, respectively.

Differentiating (35), we obtain the following first order conditions:

(37) $$\emptyset_r = a_1u^* + b_1\sigma - \frac{\lambda}{L}(a_2u^* + b_2\sigma) = 0$$

(38) $$\emptyset_L = a_1(ru^* - E(M^*)) + rb_1\sigma_L + b_1\sigma_{M^*} + L\frac{(a_1u^* + b_1\sigma)}{(a_2u^* + b_2\sigma)}\left(\frac{1-r}{L}\right).$$

$$[a_2(u^*_L - \frac{u^*}{L}) + b_2(\sigma_L - \frac{\sigma}{L}) = 0$$

(39) $$\emptyset_K = a_1ru^*_K - P_{k^*}K + b_1\sigma_K + [a_2(\frac{1-r}{L})u^*_K + b_2(\frac{1-r}{L})\sigma_K] = 0$$

(40) $$E(U_2) - U_2(W^*) = 0$$

The firm's optimization rule with respect to labor can be summarized as the following: Acquire that level of labor for which the expected utility of the marginal product of labor less monitoring costs equals the opportunity costs of labor. Fig.3.2 illustrates this rule. The firm acquires L* employees. Labor claims a share of output equal to OAEL*/OCDL*. If the firm is also a monitor, then it will claim ACDE/OCDL*. The share of output representing expected monitoring costs is BCDE/OCDL* and this would be the monitor-employee share differential if the monitor is an employee and both employee and firm have the same utility function.

The first order conditions also imply the following equili-

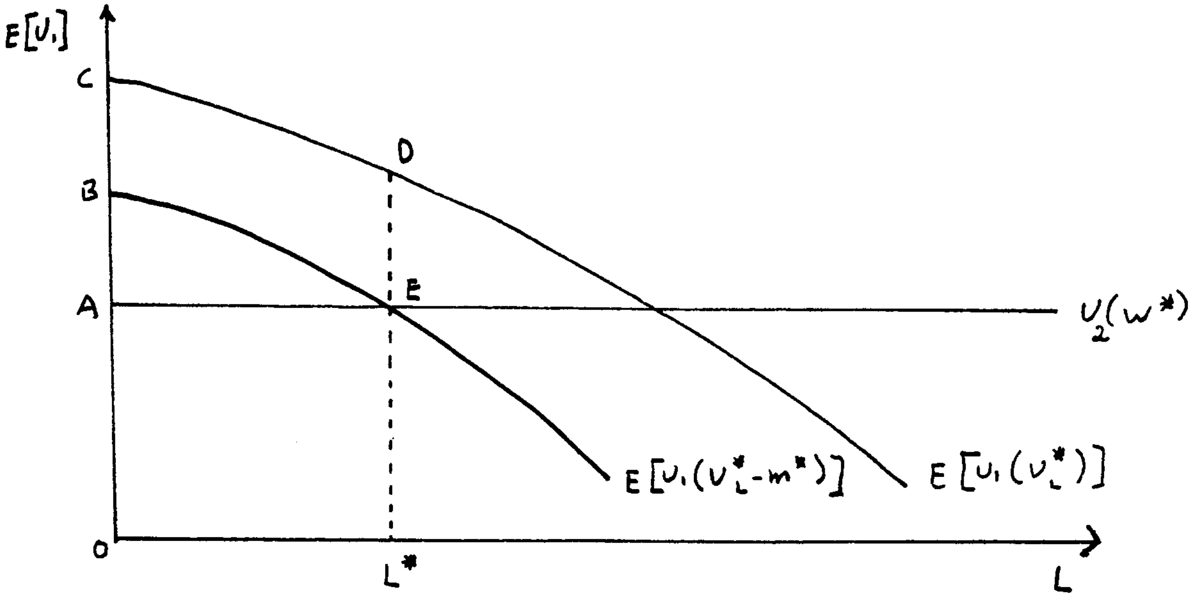

Fig. 3.2 Share Contracting, Monitoring and Risk Aversion

-brium share for the firm:

$$(41)\quad r = \frac{a_1E(M^*) - b_1\sigma_{M^*} - \left(\frac{a_1u^*+b_1\sigma}{a_2u^*+b_2\sigma}\right)[(a_2(u^*_L - \frac{u^*}{L}) + b_2(\sigma_L - \frac{\sigma}{L})]}{a_1u^*_L + b_1\sigma_L - \left(\frac{a_1u^*+b_1\sigma}{a_2u^*+b_2\sigma}\right)[(a_2(u^*_L - \frac{u^*}{L}) + b_2(\sigma_L - \frac{\sigma}{L})]}$$

The firm's share of output is a function of the mean and standard deviation of monitoring costs, the expected total, average and marginal product of labor, size of the labor force, the variance of employee output and the tastes of both firm and employee.

There are two equilibrium conditions for the employee:

$$(42)\quad E(U_2) = U_2(W^*)$$

$$(43)\quad \frac{(1-r)}{L} = \frac{1}{L}\left[1 - \frac{(a_1E(M^*)+b_1\sigma_{M^*} - \left(\frac{a_1u^*+b_1\sigma}{a_2u^*+b_2\sigma}\right)[(a_2(u^*_L-\frac{u^*}{L})+b_2(\sigma_L-\frac{\sigma}{L})]}{(a_1u^*_L+b_1\sigma_L) - \left(\frac{a_1u^*+b_1\sigma}{a_2u^*+b_2\sigma}\right)[(a_2(u^*_L-\frac{u^*}{L})+b_2(\sigma_L-\frac{\sigma}{L})]}\right]$$

The first condition (42) simply states the employee's opportunity cost constraint. The second condition (43) is the equilibri-

-um share for an individual employee, which is a function of the same parameters and variables influencing the firm's share.

The derivation of general expressions for the monitor's share and the monitor-employee share differential is somewhat more difficult. In the previous section's model, the firm was depicted as deducting expected monitoring costs from each employee's share and transferring this amount to a separate agent. Risk neutrality allowed us to dispense with consideration of any party's utility function and to bypass such issues as whether the monitor's utility function differs from the employee's.

In this general model, the tastes of the monitor must be considered in determining the share of output attributed to monitoring fees. Consider the equilibrium share for the firm in (41). Let r_1 be the share with positive expected monitoring costs (simply the expression in (41)) and r_0 be the share without such costs (the case of $E(M^*)$ and σ_{M^*} being zero). The difference (r_1-r_0) will be the fraction of output claimed at least by the <u>firm</u> as expected monitoring costs:

$$(44)\quad (r_1-r_0) = \frac{a_1E(M^*) - b_1\sigma_{M^*}}{a_1u^*_L+b_1\sigma_L-\left(\frac{a_1u^*+b_1\sigma}{a_2u^*+b_2\sigma}\right)\left[a_2\left(u^*_L-\frac{u^*}{L}\right)+b_2\left(\sigma_L-\frac{\sigma}{L}\right)\right]}$$

However, can (44) also be interpreted as a measure of compensation to a third party for monitoring services? In fact, if the monitor is also an employee, can (r_1-r_0) also be viewed as a measure of the monitor-employee share differential? The answer to the first question is yes if the third party has the same utility function as the firm. Since $(r_1 - r_0)$ depends in part on the tastes of the <u>firm</u>, it cannot be viewed as a valid measure of a third party's compensation for monitoring if the third party has different taste parameters. The answer to the second question is yes if <u>both</u> firm and employee have the same utility function. If the monitor has an utility function different from the employee, then the equilibrium employee share component of the monitor's share $(1-r)/L$ will be different from the employee's. These restrictions on the interpretation of the monitor-employee share differential could possibly be removed if a more complex optimization problem for the firm were used, perhaps incorporating a separate utility function for a third party monitor and the <u>explicit</u> assumption that the third party claims the share of output accruing to expected monitoring costs.

Focussing on the equilibrium conditions governing the employee share and the share claimed by the firm as expected monitoring costs, the general model presented generates seven special cases of $(1-r)/L$ and $(r_1 - r_0)$. We will examine each case below.

<u>Case 1</u>: Risk Neutrality/Costly Monitoring

To obtain the equilibrium conditions for the previous section's model, we must impose the restriction that both b_1 and b_2 are zero and a_1 and a_2 are equal. Since this model has already been discussed in detail, we need not discuss it here.

<u>Case 2</u>: Risk Averse Firm/Risk Neutral Labor/Costless Monitoring

If the firm is risk averse, $b_1 < 0$ and $b_2 = 0$ if labor is risk neutral. Differentiation of the employee share with respect to the standard deviation of output yields an unambiguous inverse relationship, i.e. $\partial[(1-r)/L]/\partial\sigma < 0$. Likewise, differentiation of the firm's share with respect to risk yields an unambiguous positive relationship. The firm's aversion towards risk explains this result: The firm suffers a loss in expected utility when perceived risk rises. Since the expected utility of the marginal product of labor has fallen, the firm hires less labor. A smaller labor force allows the firm to <u>raise</u> its own share, while still honoring each employee's opportunity cost constraint. Consider the following example: Suppose the expected present value of output is currently 1,000, $W^* = 50$, $r = .5$ and $L = 10$. Now suppose a rise in risk causes output to fall to 800. The firm can raise its share to .6, for example, if it lowers the size of the labor force to 6.4, without violating the opportunity cost constraint. What is important here is that the expected <u>dollar</u> compensation to each employee not fall below 50.

Case 3: Risk Averse Firm/Risk Neutral labor/Costly Monitoring. If we introduce expected monitoring costs to Case 2, we find that the employee share and output variance have an unambiguous and inverse relationship. In addition, expected monitoring costs have the effect of reinforcing the negative sign on the derivative between the employee share and output variance. This is because the firm must lower the employee share for a rise in variance, because not only must it recoup its loss in expected utility due to the effect of risk aversion, but also due to expectations of higher monitoring costs.

The fraction $(r_1 - r_0)$ and the variance of output have an ambiguous relationship as the derivative with respect to output variance has no general sign. This is because there are two effects of an increase in output variance that induce opposite effects on $(r_1 - r_0)$: (1) An increase in variance raises the firm's share due to risk aversion; (2) An increase in variance raises expected monitoring costs. The larger of the two effects determines the overall sign on $\partial (r_1 - r_0)/\partial\sigma$.

Clearly, this special case of a risk averse firm and a risk neutral labor force can generate the same prediction as to the relationship between employee shares and output variability as the previous section's model. In fact, an inverse relationship can be produced even without the assumption of positive monitoring costs. These results complement those of Stiglitz [28]. However, if we compare the predictions of the risk neutrality/costly monitoring model to Case 3 with regard to the fraction $(r_1 - r_0)$, the derivative of this share with respect to output variance is strictly positive for the former and ambiguous for the latter.

Cases 4 and 5: Risk Neutral Firm/Risk Averse Labor/Costly and Costless Monitoring.

Let us first consider the case of zero monitoring costs. We allow $b_1 = 0$ and $b_2 < 0$. The sign on $\partial[(1-r)/L]/\partial\sigma$ is <u>positive</u>, implying that firms raise employee shares if risk rises. This is an intuitively appealing result: If perceived risk rises, then employees suffer a loss in expected utility. With the opportunity cost condition $E(U_2) = U_2(W^*)$, each employee will remain with the firm as long as his/her loss in expected utility is at least made up. This condition can be satisfied by the firm raising the employee share. Employees will work in the face of increased risk only if they are compensated for the increase in risk. This result complements the results of Sutinen [31] and violates the results of Stiglitz [28].

If we introduce expected monitoring costs (Case 5) into the employee's share, we note that the employee share rises with risk as long as the effect of monitoring costs on the share is less than the effect of employee risk aversion. Both factors exert opposite effects on the share, but if expected monitoring costs are prohibitively high, the monitoring costs effect may swamp the risk aversion effect, yielding a negative sign on the derivative of $\partial[(1-r/L]/\partial\sigma$.

The derivative of $(r_1 - r_0)$ with respect to output variance is unambiguously positive, implying that the fraction of output claimed by the firm as monitoring costs will always rise with the variance of output.

Cases 6 and 7: Firm and Labor Risk Averse/Costly and Costless Monitoring.

Here we presume b_1 and $b_2 < 0$. To simplify the differentiation, allow both parties to have the same marginal expected utilities of expected value and risk, i.e. $a_1 = a_2$ and $b_1 = b_2$. With zero expected monitoring costs, differentiation of the employee share with respect to risk yields a curious result: The employee share and risk are negatively related. These results seem to suggest that as long as the firm is risk averse, an increase in risk will always result in a lower employee share. One rationale for this is the following: If risk rises, the firm suffers a drop in expected utility. To recoup its loss, it lowers the employee's share. Holding the number of employees constant, a reduction in the employee share clearly violates the constraint of a competitive labor market. But, the firm can always maintain the worker's expected utility at $U_2(W^*)$ if it lowers the number of workers L. Clearly $[(1-r)/L](u^*)$ can be unchanged if r rises and L falls. Thus, the firm may engage in two actions if perceived risk rises: (1) Lowering the employee share; (2) Reducing the size of the labor force.

If we introduce expected monitoring costs into the model (case 7), then these costs would reinforce the inverse relationship between employee shares and the variance of output. These results indirectly violate the results of Stiglitz [29], who would predict no sign at all on $\partial[(1-r)/L]/\partial\sigma$ for this case. The sign on $\partial(r_1 - r_0)/\partial\sigma$ is unambiguously positive. This is perhaps due to the fact that there are two effects that simultaneously reinforce the positive sign - expected monitoring costs and risk aversion by the firm.

From this survey of the seven special cases of the general model, equilibrium shares vary on a case-by-case basis, since the equations expressing each share are different for each case. There is definite overlap between the cases in the signs on $\partial[(1-r)/L]/\partial\sigma$, $\partial r/\partial\sigma$ and $\partial(r_1 - r_0)/\partial\sigma$, as well as the signs on the derivatives of these shares with respect to other parameters (such as u*, L, etc.). For example, six of seven cases could predict an inverse relationship between employee shares and output variance, provided certain conditions held for each case.

Testing Theories of Shares and Output Variability

Suppose we sought to estimate the equation for the equilibrium employee share from the sixth special case studied in the previous section - the case of both sides being risk averse with zero expected monitoring costs. We note that the equilibrium employee share is the following:

$$(45)\quad \frac{(1-r)}{L} = \frac{1}{L}\left(1 + \frac{a_2(u^*_L - \frac{u^*}{L}) + b_2(\sigma_L - \frac{\sigma}{L})}{a_1 u^*_L + b_1\sigma_L - [a_2(u^*_L - \frac{u^*}{L}) + b_2(\sigma_L - \frac{\sigma}{L})]}\right)$$

If the equation used for estimation was exactly identical to the theoretical equation above, then clearly the estimation procedure would constitute an unambiguous test of this special case. Likewise, if we were interested in estimating equations for employee shares from any of the other six cases of the general model, then each test would be unambiguous if and only if the equations used for estimation were identical to the theoretical equations obtained from the choice problem of the firm.

Suppose, however, that only linear or log-linear regression techniques were used to estimate the employee share for the sixth special case. Then a linear regression equation ap-

-proximating (45) might be the following:

$$(46)\ \frac{(1-r)}{L} = d_0 + d_1u^*_L + d_2u^* + d_3L + d_4 + e$$

We posit that $d_0 = 0$, $d_1, d_2 > 0$, $d_3, d_4 < 0$ and e is a classically well-behaved error term.

Other cases of (1-r)/L could also be approximated by the same regression equation above, and they could also imply the same signs on the regression coefficients. As a matter of fact, if only linear regression techniques were available, it would be close to impossible to distinguish between a regression of (1-r)/L for one case from another. In short, linear tests of shares based on a theory of share contracting with risk aversion could never be unambiguous.

It is obvious that the theoretical equations for (1-r)/L, r and $(r_1 - r_0)$ are extremely difficult to estimate, even with non-linear estimation techniques. The primary source of the problem is that most of the explanatory variables in each equation appear several times throughout the equation, requiring at the least a non-linear iterative estimation technique (simulation or numerical analysis, for example), clearly outside of the bounds of conventional estimation techniques. Even if required estimation techniques were available, estimation error may be so large that it might be impossible to distinguish a test based on one case from another. In the final analysis, it is thus empirical intractability that causes a risk aversion theory of share contracting to be in practice irrefutable. This may well explain why virtually no empirical work has been done on risk aversion and share contracting.

There is only one of the seven special cases of the general model for which the equilibrium share equations can be estimated directly. This is the risk neutrality/costly monitoring model derived earlier in this chapter. For example, consider the monitor-employee share differential equation from that model, $Z = \gamma\sigma^2 L/u^*$. This equation can be estimated directly through the estimation of a log-linear regression equation for Z. Likewise, the equations for $(1-r)/L$, $(1-r)$, S and r can be estimated directly as well.

Despite the fact that the risk neutrality/costly monitoring model is the only testable case, we still have the following problem: suppose that employee shares were regressed on u^*, σ^2, u^*_L and L, and observed signs were all in the hypothesized directions. We still could not deny the possibility that the underlying model of share contracting is one of the risk aversion cases, rather than the risk neutrality case, since all cases are capable of generating the same comparative static results on employee shares as the risk neutrality case.

Consider the monitor-employee share differential Z. From the previous section, the differential could only be positive if monitoring costs were positive. In addition, the risk neutrality case predicted $\partial Z/\partial\sigma^2 > 0$, $\partial Z/\partial L > 0$ and $\partial Z/\partial u^* < 0$. The same predictions could be obtained from any of the remaining cases of the general model provided that the model incorporated costly monitoring (and provided that the equilibrium share of output claimed by the firm as expected monitoring costs (44) could validly be interpreted as a third party monitor's com-

-pensation for monitoring services).

Our general model predicts that share differentials exist between two classes of workers (monitors and employees) due to monitoring costs. But in general, there is another possible explanation of pay differentials based exclusively on risk aversion: pay differentials exist due to differences in the bearing of risk. The following question arises: can a firm accomodate differential risk-taking within a pure share contract through the payment of different shares? For example, suppose there are two workers A and B, and A bears more risk than B. If the firm offered A a larger share than B, then since the contracts offered to both workers are perfectly correlated, A's contract would unambiguously dominate B's contract, perhaps causing the defection of B from the firm.

In general, we can rule out differential risk-taking as an explanation of pay differentials if firms choose the same contract for all workers. Differential risk-taking is caused by differences in risk aversion across workers. Firms can offer a spectrum of contracts from pure time rate to pure piece/share, the latter being the most risky form of contract for the employee. Firms can accomodate differences in risk aversion across workers by offering different contracts to different workers. For example, those workers most willing to bear risk can be offered contracts with larger fractions of compensation based on piece/share pay. Observing mixed contracts with different workers receiving different fractions of compensation based on time and piece/share pay would be an indication of differential risk-taking. Thus, one reason firms may choose the same type of contract (such as pure share) for all workers is the non-existence of risk differentials between workers. It follows that in a test of the monitor-employee share differential, a way of excluding differential risk-taking as an explanation of share differentials is the use of a sample of firms choosing only pure share contracts. The monitor-employee share differential thus constitutes an unambiguous test of monitoring in pure share contracts.

Footnotes to Chapter 3

1. It has been customary in previous literature to treat total output of the firm as a random variable rather than employee-specific output. For example, Stiglitz [28] treats total firm output (Q) as a stochastic constant returns to scale function:

(i) $Q = g(\theta)F(L,T)$

where T=land, θ is a random variable and F is a continuously differentiable production function. Sutinen [31,32] expresses total revenue as Qu, where u is a positive random variable.

2. We ignore the possibility that the firm may deduct certain fixed and/or variable expenses before determining shares.

3. For analytical simplicity we define risk in terms of standard deviation, rather than variance. Use of variance would lead to the same qualitative results, but a much more tedious analysis.

4. Testing for Monitoring in Share Contracts: An Application to Commercial Fishing

The purpose of this chapter is to present a test of the risk neutrality/costly monitoring model of the previous chapter through the estimation of the share differential equation (Z). The differential between a monitor's share of output and an employee's share was found to be $Z = \gamma \sigma^2 L/u^*$. The comparative static results yielded positive relationships between the differential and output variance σ^2 and employees L and an inverse relationship between the differential and conditional expected value of firm output, u*.

A fertile area for testing this hypothesis is the commercial fishing industry. In that industry, nearly all employees on fishing vessels are compensated via a pure share system (no fixed wages or rents) and on almost all vessels, owners assign the responsibility of monitoring crew members to the skipper (if the skipper is not the owner). While monitoring is the skipper's primary responsibility, other duties may include the location of fishing grounds, navigation of the vessel, obtaining supplies and groceries for crew members, etc. Except on very large vessels, skippers <u>also</u> participate in the harvesting of catch. Thus, the skipper is both a monitor and crew member.

A survey of vessel owners on the Oregon Coast during the Summer of 1985 revealed the following observations on compensation arrangements of skippers and crew members during the 1984 season:

(1) Crew and skipper shares are stipulated before the season be-

-gins;

(2) The size of the crew share can vary according to the level of experience. There are typically three classes of experience: (a) "Green" - a crew member with less than one month of experience; (b) "Learning to Sew" - a crew member with between one and six months of experience. This type of crew member is usually sufficiently skilled to participate in harvest, but is usually not adequately skilled in dealing with such potential problems as net or equipment repair; (c) "Experienced Web Man" - a crew member with an average of at least six months of experience with acceptable skills in all phases of production except the skipper's duties. Usually, the skipper is the most experienced crew member on board;

(3) On almost all vessels, skippers are paid a share larger than a crew member. Vessel owners report that skippers are paid a "premium" over the crew share as compensation for their duties separate from the harvesting of fish;

(4) Skipper shares, crew shares and the spreads between them typically vary across different species and vessel sizes;

(5) Heterogeneity of crew shares typically occurs on vessels employing high quality crew members, whereas homogeneity typically occurs on smaller and less productive vessels;

(6) Intra-seasonal changes in crew shares occur primarily for those crew members elevated from "green" status to "learning to sew" and from "learning to sew" to "experienced web man," but in most other cases, crew shares are fixed throughout the season;

(7) There are typically no written agreements on compensation;

(8) If a crew member is found to be performing below expectation mid-season, he is usually fired rather than having his crew share reduced. For this reason, except for cases alluded to in (6), evidence of mid-season monitoring is labor turnover. If a crew member is found to be performing above expectation mid-season, his share may be increased only if the vessel owner perceives that raising the share would not induce antagonism from remaining crew members. In cases of expected antagonism, the vessel owner may advance the status of the crew member to alternate skipper, promise him indefinite tenure and a positive recommendation to other firms, etc;

(9) The skipper's required effort in monitoring usually varies across species. For example, in midwater trawl it is usually much more difficult for the skipper to keep an eye on the crew because he must stay close to equipment and the helm. On the other hand, on salmon trollers and crab trawlers, monitoring is typically easier because the skipper works closely with crew members.

In addition to these observations of compensation arrangements during the 1984 season, trip-by-trip vessel-specific catch variability during the season appears, on average, to vary according to species caught and vessel size. Table 1 presents the averages of vessel-specific coefficients of variation of catch, according to species, for vessels fishing off the Oregon Coast during 1984. The average coefficient of variation for each species was obtained by calculating the trip-by-trip coefficient of variation of catch for each of a random sample of vessels and

Table 1. Catch Dispersion Across Species in Oregon during 1984.

Species	Coefficient of Variation	Sample Size/Pop.
Columbia River Sal.	1.22	.03
Scallops	.75	1.0
Black Cod Longline	.81	1.0
Black Cod Pot	.67	1.0
Midwater Trawl	.61	.15
Shrimp	.71	.24
Tuna	.39	.08
Crab	.90	.05
Halibut	.24	1.0
Squid	1.04	1.0
Bottom Trawl	.76	.12
Troll Salmon	1.04	.02

Table 2. Catch Dispersion According to Vessel Length for Bottom Trawlers Only in Oregon during 1984.

Vessel Length	Coefficient of Variation	Sample Size/Pop.
45-49 ft.	1.20	.01
55-59	1.04	.03
60-65	.63	.01
65-69	.56	.02
70-74	.64	.02
75-79	.64	.06
80+	.57	.03

Source for both Tables: Oregon Department of Fish and Wildlife averaging these coefficients. The far right column shows the percentage of the total population of boats in each species category used in the calculation of each coefficient. For scallops, black cod longline, black cod pot, halibut and squid, the average coefficient of variation was calculated using all boats in the population. For the remaining species, random samples averaging 15 vessels, an average of 10 percent of the population of vessels in each species category were used.[1/] The table clearly indicates a variation in catch dispersion across species. Table 2 presents a breakdown of trip-by-trip vessel-specific average coefficients of variation for random samples of bottomfish trawlers in 7 different vessel length categories. The samples averaged 4 vessels per category, an average of 4 percent of the total population of bottom trawlers. The figures indicate that, on average, catch dispersion and vessel length are negatively correlated for bottom trawlers. There is a general explanation for this: larger vessels tend to be equipped with more sophisticated equipment for locating and harvesting fish, allowing for greater consistency in trip-by-trip catch.

Given all these observations of the Oregon commercial fishing industry, it appears that our hypothesis could be tested using data from that industry. With observations on the skipper-crew share differential, the variance of vessel-specific catch, the number of crew members and mean vessel-specific catch, the natural logarithm of equation (1) could be estimated using ordinary least squares:

$$(2)\ \ln(Z) = \ln(\gamma) + \ln(\sigma^2) + \ln(L) - \ln(u^*)$$

The multiple regression equation used for estimation would be the following:

$$(3)\ \ln(Z) = b_0 + b_1\ln(\sigma^2) + b_2\ln(L) + b_3\ln(u^*) + e$$

$$\text{where: } b_0 = \ln(\gamma)$$

$$b_3 = -1,\ b_1 = b_2 = 1$$

Before discussing the data actually collected, let us consider how each of the variables might be measured. Recall that in the costly monitoring/risk neutrality model from the previous chapter, the conditional expectation and variance of output are estimates formulated by the firm prior to production. Obtaining observations on u^* and σ^2 is tantamount to obtaining proxies for these estimates. Clearly, we are not totally sure as to the information vessel owners use in formulating values for these parameters. A survey of Oregon Coast fishermen revealed that fishermen rely primarily on historical catch data. This catch data could be specific to each owner's vessel, a cross section of vessels in his species-vessel length category, or home port. Therefore, it appears reasonable that we use historical vessel-specific average catch and variance of catch as proxies for u^* and σ^2, respectively.

A random sample of 31 vessel owners, who were not skippers of their own boats, on the Oregon Coast during the 1984 season was taken during the Summer of 1985. Vessel owners were asked to give the following information: (1) Crew and skipper shares paid during the season; (2) The average number of crew members aboard during the season; (3) Trip-by-trip catch data for the season; (4) Whether any crew member's share had been altered and whether there had been any labor turnover during the season; (5) Crew shares for "green," "learning to sew," and "experienced web man" crew members.

Table 3 at the end of the chapter presents the information obtained from the 31 vessel owners. In constructing the sample, an effort was made to sample from as many different vessel length-species categories as possible. Vessel owners in all species categories listed in Table 1 were interviewed except squid. The observations for Columbia River gillnet salmon are estimates submitted by the vessel owner for a "typical" boat in that species category. The owner was not willing to divulge any information specific to his vessel on grounds of confidentiality, but only his estimates of variables for the whole population of vessel owners. From Table 3, twelve vessels reported harvesting multiple species and six of these twelve vessels reported different shares and different share differentials for different species. In general, the vessel owners reporting this phenomenon explained that variability in production costs (due primarily to variability in catch) and market conditions induced them to vary shares according to species.

For 16 of the owners interviewed, information on mid-season labor turnover and alteration of crew shares was not available. For the remaining 15 owners, such information was available and eight reported firing crew members during the season due to dissatisfaction in performance. In addition, five owners reported altering crew shares for crew members who were either elevated from "green" to "learning to sew" or the latter to "experi-

-enced web man." For these last 15 vessels, this is solid evidence of mid-season monitoring activities of skippers.

Trip-by-trip catch data for each vessel surveyed were not available, due to confidentiality, lack of recordkeeping and a lack of willingness of vessel owners to spend the time gathering the data for the survey. To resolve this problem, consider the fact that all vessel owners must submit trip-by-trip catch data to the Oregon Department of Fish and Wildlife (ODFW). However, ODFW can only release this data to the public if the identity of the vessel owner is not made available. Thus, proxies for average catch and variance of catch for each vessel had to be devised. First, the 31 vessels surveyed were classified according to species-vessel length (10 foot intervals) categories. For example, a 46 foot bottomfish trawler constituted an observation in the 40-49 foot bottomfish trawler category. For each category containing observations, a random sample averaging 15 vessels in the ODFW data bank was taken and the average mean catch and average variance of catch were calculated. Secondly, the calculated average mean catch and average variance of catch were used as proxies for u* and σ^2, respectively, for each observed vessel. For example, in obtaining the proxies for u* and σ^2 for the 46 foot bottomfish trawler mentioned earlier, a random sample of approximately 15 vessels was taken from the population of 40-49 foot bottomfish trawlers and the average mean catch and average variance of catch from this sample were used as estimates of that trawler's mean and variance of catch for the season.

Because twelve vessels reported harvesting more than one species, a problem arose in deciding in which vessel length-species category each of these vessels belonged. For example, vessel 5 (from Table 3) harvested three species. In which vessel length-species category should the vessel belong - crab 40-49 ft., bottom trawl 40-49 ft., or shrimp 40-49 ft? There are two factors specific to the data in Table 3 that make this issue very important. The first is that from the survey, it was not known which species were the dominant species harvested on each of the 12 vessels reporting multiple species. The second is the fact that six of the twelve vessels reporting multiple species also reported multiple share arrangements, usually one for each species. For example, vessel 6 reported a crew share for crab that differed from black cod pot. For that vessel, there were effectively two types of stipulated share contracts, one for each species. We also observe that some vessels, such as 15, report identical shares for both types of species. This is equivalent to saying that the vessel owner created two identical share contracts - one for each species.

A general interpretation of the share data in Table 3 is that vessel owners create species-specific share contracts. This is clearly because market and production conditions differ across species. Any vessel categorization scheme would have to incorporate this observed behavior. Therefore, since 31 surveyed vessel owners created a total of 46 share contracts (since the 31 vessels reported harvesting a total of 46 species, many of course being identical), 46 vessel length-species categories were created for the regression of equation (3). For example, vessel 5 was classified into three different vessel length-species categories (crab 40-49 ft., bottom trawl 40-49 ft. and shrimp 40-49 ft.), taking into account the observation that three share contracts were created by that vessel owner, two being identical for shrimp and crab and one for bottom trawl.

Table 4 (end of chapter) lists all 46 vessel length-species categories, the surveyed vessel numbers corresponding to each category, the natural logarithms of average mean catch (the estimate of the surveyed vessel's mean catch for the 1984 season) and the average variance of catch (the estimate of the surveyed vessel's variance of catch for the 1984 season) for each category, and the percentage of the total population of boats used in calculating average mean catch and average variance of catch.

In the regression of (3), there were accordingly 46 observations on each variable. One problem arose with the use of a log linear regression equation: Four of the observations on Z had values of zero. Since $\ln(Z=0)$ is in the limit equal to $-\infty$, the regression should employ $-\infty$ for these four observations. However, any regression is obviously impossible with observations of ∞ or $-\infty$. Two steps were taken in an attempt to remedy this problem. First, a regression equation was estimated with the omission of the four observations. The 42 observations used for this regression are listed according to variable in Table 5. With ordinary least squares, the following estimated equation was obtained:

$$\begin{array}{llllllll}
(4)\ \ln(Z) = & 1.88 & + & .62\ln(L) & - & .28\ln(u^*) & + & .10\ln(\sigma^2) \\
 & (.58) & & (.35) & & (.09) & & (.06) \\
 & (3.21) & & (1.77) & & (-3.23) & & (1.89) \\
 & R^2 = .25 & & & & F(3/42) = 4.27 & &
\end{array}$$

The first numbers in parentheses under each coefficient are the standard errors of the estimated coefficients and the second numbers in parentheses are the t statistics.

All signs on the coefficients are as hypothesized and statistically significant at the five percent level. Given the F statistic, the equation as a whole is significant at the five percent level. In addition, strong multicollinearity between $\ln(u^*)$ and $\ln(\sigma^2)$ was present, but this is mostly due to the fact that identical pairs of observations of u^* and σ^2 are used in the regression. For example, because a large number of observations from the bottom trawl 70-79 ft. category were used, the proxies for $\ln(u^*)$ and $\ln(\sigma^2)$ from that category are used a large number of times. This repeated use of the same pairs of observations creates a natural correlation between those observations. No evidence of heteroskedasticity was found. Overall, these results offer strong support for the hypothesis that the share differential is a measure of expected monitoring costs.

The second step was to perform regressions using all 46 observations (including the four observations for which Z = 0). For these four observations (listed in Table 6), values of Z close to zero were used. This was done to determine how sensitive the regression results were to the inclusion of the four supplementary observations and to changes in the values of Z used for those observations. In the first regression a value of Z=1 (ln(Z)=0) was used. The following regression results were obtained:

$$
(5)\quad \begin{array}{llllllll} \ln(Z) = & 2.03 & + & .34\ln(L) & - & .28\ln(u^*) & + & .10\ln(\sigma^2) \\ & (.84) & & (.45) & & (.13) & & (.08) \\ & (2.40) & & (.87) & & (-2.18) & & (1.26) \end{array}
$$

$$
R^2 = .12 \qquad\qquad F(3/42) = 1.87
$$

In a second regression, a value of Z=.05 (ln(Z)=-3) was used, with the following results:

$$
(6)\quad \begin{array}{llllllll} \ln(Z) = & 2.26 & + & .19\ln(L) & - & .27\ln(u^*) & + & .08\ln(\sigma^2) \\ & (1.75) & & (.92) & & (.26) & & (.16) \\ & (1.30) & & (.21) & & (-1.02) & & (.42) \end{array}
$$

$$
R^2 = .03 \qquad\qquad F(3/42) = .47
$$

Inclusion of the four observations of Z=1 and Z=.05 resulted in a significant change in the regression results. Not only was there a deterioration in the fit of the data to the theory, but as smaller values of Z were used, this deterioration was reinforced. This is because the four observations are outliers. For example, the theory predicts that low values of Z will be associated with low values of L and and high values of u*. For the 42 observations listed in Table 5 , the average value of ln(L) is 1.11 and the average value of $\ln(\sigma^2)$ is 16.89. However, the average values of ln(L), $\ln(\sigma^2)$ and ln(u*) for the four supplementary observations are 1.17, 17.37 and 9.16, respectively. If the four observations had contained low values for output variance and crew members and high observations for mean catch, then their inclusion would have strengthened the fit of the data to the theory. Overall, since these four observations make up only nine percent of the total data set, we may conclude that the data set as a whole fits the theory well.

In another regression, the vessel length-species categories were broadened and reduced to eighteen in number. This was done in order to determine whether cross sectional differences in monitoring behavior were detectable from more aggregated data. <u>Table 7</u> presents the observations used for this regression. Since the vessel length-species categories were widened, six categories contained multiple vessels. For these categories, the averages of the share differentials (including the four extra Z=0 observations) and crew sizes were used. Observations on average mean catch and average variance of catch were calculated on the basis of random samples of vessels in these categories. <u>Table 7</u> indicates the fraction of the population of boats that were samples in each category. Using eighteen observations on each variable, the following estimated equation was obtained:

$$\begin{array}{llllllll} (7)\ \ln(Z) = & .52 & - & .06\ln(L) & - & .26\ln(u^*) & + & .22\ln(\sigma^2) \\ & (1.02) & & (.35) & & (.21) & & (.12) \\ & (.51) & & (-.16) & & (-1.26) & & (1.74) \end{array}$$

$$R^2 = .2,\ F(3/14) = 1.18$$

The signs of the coefficients for the intercept, expected catch and variance of catch are in the hypothesized directions, but the sign on crew members is not. The coefficient of particular interest is the variance of catch. The coefficient on variance is significant at approximately the six percent level. The intercept, crew members and mean catch are insignificant at the five percent level. The regression equation as a whole is insignificant at the five percent level.

The strongest support for our hypothesis is provided by the results of equation (4). On the basis of that equation, our empirical results offer support for our hypothesis. The results must be interpreted with regard to the four outlier observations not used in (4), the apparent multicollinearity between mean and variance of catch, the lack of vessel-specific catch data and the relatively small number of observations used in the formulations of the proxies for mean and variance of catch. The explanatory power of the share differential equation would be more apparent with the use of trip-by-trip catch data, but we may conclude on the basis of all of our results that the equation fits the data well.

Footnotes to Chapter 4

1. The average coefficients of variation of catch were calculated using vessel-specific catch data supplied by Christopher Carter of the Oregon Department of Fish and Wildlife. Due to the high costs of obtaining this data, random samples averaging only 15 vessels were feasible.

Table 3. Compensation and Vessel Data for a Random Sample of Oregon Commercial Fishing Vessel Owners.

#	Length	Skipper Share	Crew Share	Crew	Species	Comments
1	70-74	19%	10%- Green 12 - Learning to Sew 14 - Exp. Web Man	3	Midwater, Bottom T	No Turnover, Alteration of Share
2	"	"	"	"	Shrimp, Bottom T	Turnover Alteration of Share
3	"	"	"	"	"	
4	50-54	25	10 - Green 12.5 - LTS 14 - Exp	3	Black Cod LL	Alteration of Share
5	45-49	30	12-2 Man/BT 18-1 Man/BT 15-2 Man/Crab and Shrimp	3[1/]	Crab, Bottom T, Shrimp	Turnover
6	40-44	25	13-2 Man/Crab 8,10,12 for Black Cod Pot Depending on Experience	3	Crab, Black Cod Pot	Alteration of Share
7	45-49	25 w/ 1 Man Crew 20 w/ 2 Man Crew	20 - 1 Man 12 - 2 Man	3[2/]	Bottom T, Shrimp	
8	50-54	20	7 - Green 10 - Exp. WM	3	Bottom T	Turnover, Alteration of Share
9	45-49	Z = 0			Bottom T	
10	45-49	23	12.5 - 2 Man/ Bottom T 20 - 1 Man/ Bottom T 15 - 2 Man/ Crab	3	Bottom T, Crab	Turnover
11	70-74	18	10	4	Bottom T	
12	75-79	20	12 - 3 Man/ Bottom T 6 - 5 Man/ Scallops	3 /BT 5 /Sc	Bottom T Scallops	Turnover

Table 3. (Cont.)

#	Length	Skipper Share	Crew Share	Crew	Species	Comments
13	75-79	17	11	3	Bottom T	
14	55-59	25	8	6	Halibut	Turnover
15	60-64	25	20 -Exp 15 -Green	2	Tuna, Salmon	
16	75-79	15	10	3	Bottom T	
17[3]	70-74	10- Crab, Shrimp Z = 0 - Halibut	8- Crab & Shrimp	4	Crab, Shrimp, Halibut	
18	50-54	18- Salmon, Tuna Z = 0 - Halibut	15- Salmon, Tuna	3	Salmon, Tuna, Halibut	
19	40-44	25	20	3	Bottom T	
20	50-54	15	12	3	Crab, Bottom T	
21	55-59	20	10	3	Bottom T	
22[4]	65-69	Z = 0			Bottom T	
23	75-79	15	10.5	3	Bottom T	
24	75-79	15	6.7	4	Bottom T	
25	75-79	16	8	4	Bottom T	
26	75-79	12	8	4	Bottom T	
27	75-79	17	11	3	Bottom T	
28[5]	75-79	15	10.5	3	Bottom T	
29	80+	15	11	3	Bottom T	
30	65-69	17	11	3	Bottom T	
31	40-49	25	12.5	2	Col. R. Salmon	

Sources: Personal Interviews

Nicholas Furman, Commercial Fisherman

Albert Gann, Commercial Fisherman

Elma Marxen, Accountant

Hans Rodtke, Economic Consultant

Footnotes to Table 3

1. On this vessel, crew size varied on a trip-by-trip basis. The vessel owner was asked to specify the most common crew size used. The most commonly reported crew size is the crew size listed in the table and used in the regressions.

2. Ibid.

3. On this vessel, the owner specified that the crew and skipper shares were equal, but did not assign numbers to those shares.

4. Ibid.

5. On this vessel, there was a dispersion of crew shares. The number listed in the table is the mean share.

Table 4. Estimated Mean Catch and Variance of Catch for Vessels in 46 Species-Length Categories.

Vessel #	Length-Species Category	ln(u^*)	ln(σ^2)	Sample/Pop.
1	Midwater Trawl 70-79	10.2	19.45	.154
1	Bottom Trawl 70-79	10.06	19.17	.06
2	Shrimp 70-79	11.11	16.24	.08
2	Bottom Trawl 70-79	10.06	19.17	.06
3	Bottom Trawl 70-79	10.06	19.17	.06
3	Shrimp 70-79	11.11	16.24	.08
4	Black Cod LL 50-59	8	15.67	.58
5	Crab 40-49	6.8	14.25	.01
5	Bottom Trawl 40-49	8.09	16.27	.03
5	Shrimp 40-49	5.92	12.18	.05
6	Crab 40-49	6.8	14.25	.01
6	Black Cod Pot 40-49	9.15	17.84	.83
7	Bottom Trawl 40-49	8.09	16.27	.03
7	Shrimp 40-49	5.92	12.18	.05
8	Bottom Trawl 50-59	9.07	17.67	.03
9	Bottom Trawl 40-49	8.09	16.27	.03
10	Bottom Trawl 40-49	8.09	16.27	.03
10	Crab 40-49	6.80	14.25	.01
11	Bottom Trawl 70-79	10.06	19.17	.06
12	Bottom Trawl 70-79	10.06	19.17	.06
12	Scallops 70-79	8.1	18.81	.78
13	Bottom Trawl 70-79	10.06	19.17	.06
14	Halibut 50-59	8.41	14.85	.08
15	Troll Salmon 60-69	6.32	14.8	.004
15	Tuna 60-69	8.43	14.92	.02
16	Bottom Trawl 70-79	10.06	19.17	.06
17	Crab 70-79	7.11	14.51	.01
17	Halibut 70-79	6.65	10.7	.01
17	Shrimp 70-79	11.11	16.24	.08
18	Tuna 50-59	9.43	17.23	.06
18	Troll Salmon 50-59	6.01	12.19	.014
18	Halibut 50-59	8.41	14.85	.08
19	Bottom Trawl 40-49	8.09	16.27	.03
20	Crab 50-59	8.22	13.91	.01
20	Bottom Trawl 50-59	9.07	17.67	.03
21	Bottom Trawl 50-59	9.07	17.67	.03
22	Bottom Trawl 70-79	10.06	19.17	.06
23	Bottom Trawl 70-79	10.06	19.17	.06
24	Bottom Trawl 70-79	10.06	19.17	.06
25	Bottom Trawl 70-79	10.06	19.17	.06
26	Bottom Trawl 70-79	10.06	19.17	.06
27	Bottom Trawl 70-79	10.06	19.17	.06
28	Bottom Trawl 70-79	10.06	19.17	.06
29	Bottom Trawl 70-79	10.06	19.17	.06
30	Bottom Trawl 70-79	10.06	19.17	.06
31	Col. R. Salmon 40-49	5.19	12.65	.03

Source: Oregon Department of Fish and Wildlife

Table 5. Observations Used in Regression Equations (4)-(6).

#	Vessel #	ln(Z)	ln(L)	ln(u*)	ln(σ^2)	Sample/Pop	Category
1	1	1.61	1.1	10.2	19.45	.15	MW 70-79
2	1	1.61	1.1	10.06	19.17	.06	BT 70-79
3	2	1.61	1.1	11.11	16.24	.08	Sh 70-79
4	2	1.61	1.1	10.06	19.17	.06	BT 70-79
5	3	1.61	1.1	10.06	19.17	.06	BT 70-79
6	3	1.61	1.1	11.11	16.24	.08	Sh 70-79
7	4	2.40	1.1	8	15.67	.58	BC LL
8	5	2.71	1.1	6.8	14.25	.01	Cr 40-49
9	5	2.48	.69	8.09	16.27	.03	BT 40-49
10	5	2.71	1.1	5.92	12.18	.05	Sh 40-49
11	6	2.48	1.1	6.8	14.25	.01	Cr 40-49
12	6	2.56	1.1	9.15	17.84	.83	BC Pot
13	7	2.08	1.1	8.09	16.27	.03	BT 40-49
14	7	2.08	1.1	5.92	12.18	.05	Sh 40-49
15	8	2.30	1.1	9.07	17.67	.03	BT 50-59
16	10	2.35	1.1	8.09	16.27	.03	BT 40-49
17	10	2.08	1.1	10.06	19.17	.01	Cr 40-49
18	11	2.08	1.39	10.06	19.17	.06	BT 70-79
19	12	2.08	1.1	10.06	19.17	.06	BT 70-79
20	12	2.64	1.61	8.1	18.81	.78	Sc 70-79
21	13	1.79	1.1	10.06	19.17	.06	BT 70-79
22	14	2.83	1.79	8.41	14.85	.08	H 50-59
23	15	1.61	.69	6.32	14.8	.004	TS 60-69
24	15	1.61	.69	8.43	14.92	.02	T 60-69
25	16	1.61	1.1	10.06	19.17	.06	BT 70-79
26	17	.69	1.39	7.11	14.51	.01	Cr 70-79
27	17	.69	1.39	11.11	16.24	.08	Sh 70-79
28	18	1.1	.69	9.43	17.23	.06	T 50-59
29	18	1.1	.69	6.01	12.19	.014	TS 50-59
30	19	1.61	1.1	8.09	12.67	.03	BT 40-49
31	20	1.1	1.1	8.22	13.91	.01	Cr 50-59
32	20	1.1	1.1	9.07	17.67	.03	BT 50-59
33	21	2.3	1.1	9.07	17.67	.03	BT 50-59
34	23	1.50	1.1	10.06	19.17	.06	BT 70-79
35	24	2.12	1.39	10.06	19.17	.06	BT 70-79
36	25	2.08	1.39	10.06	19.17	.06	BT 70-79
37	26	1.39	1.39	10.06	19.17	.06	BT 70-79
38	27	1.79	1.1	10.06	19.17	.06	BT 70-79
39	28	1.50	1.1	10.06	19.17	.06	BT 70-79
40	29	1.39	1.1	10.13	19.48	.03	BT 80-89
41	30	1.79	1.1	9.74	18.42	.04	BT 60-69
42	31	2.53	.69	5.19	12.65	.03	CRSal.

Sources: Oregon Department of Fish and Wildlife - Catch Data
Personal Interviews- Non-Catch Data
Nicholas Furman - "
Hans Rodtke - "
Elma Marxen - "

Albert Gann - "

Table 6. Supplementary Observations Used in Regression Equations (5) and (6)

#	Vessel Number	ln(Z)	ln(L)	ln(u*)	ln(σ^2)
1	9	0,-3	.69	8.09	16.27
2	17	0,-3	1.1	10.06	19.17
3	18	0,-3	1.1	10.06	19.17
4	22	0,-3	1.79	8.41	14.85

Table 7. Observations Used for Regression Equation (7).

#	Vessel Numbers	ln(Z)	ln(1)	ln(u*)	ln(σ^2)	Sample/Pop.
1	14,18	2.14	1.70	8.41	14.85	.08
2	17	0	1.8	6.65	10.7	.01
3	31	2.53	.69	5.19	12.65	.03
4	5-9,19-21	2.30	1.00	8.69	17.19	.05
5	1-3,11-13,16, 22-28,30	1.86	1.26	9.95	18.93	.10
6	29	1.39	1.1	10.13	19.48	.03
7	12	2.64	1.61	8.81	18.09	.78
8	4	2.3	1.1	8.0	15.67	.58
9	6	2.56	1.1	9.15	17.84	.83
10	1	1.61	1.39	10.2	19.45	.15
11	5,6,10,20	2.3	1.1	7.63	14.08	.02
12	17	.69	1.39	7.25	14.56	.02
13	18	1.1	.69	6.01	12.19	.014
14	15	1.61	.69	6.32	14.8	.003
15	18	1.1	.69	9.43	17.23	.06
16	15	1.61	.69	8.43	14.92	.02
17	5,7	2.3	.92	5.92	12.18	.05
18	1-3,17	1.61	1.34	11.11	16.24	.08

Sources: Same as Table 5

5. Suggestions for Further Research

This thesis has presented two models and one test of employee output measurement monitoring of firms. The principal objective of the thesis was to obtain a testable theory of output measurement monitoring with implications for labor earnings, based on an explicit specification of the firm's monitoring technology. The two models had four basic components. First, each employee's marginal product was a normally distributed random variable with unknown mean and known variance. Second, both sides of the market were risk neutral. Third, each side of the market was equally uninformed about expected value of marginal product. Fourth, monitoring was treated as a costly hypothesis test where the objective of the test was to estimate the expected value of employee marginal product. The test was conducted through the periodic sequential sampling of output from each employee's distribution. Firms were depicted as formulating expectations of employee monitoring time and costs and incorporating these expectations into provisional wage offers. The principal comparative static result was an inverse relationship between labor income (wages and shares) and the variance of employee marginal product. This implication was tested on share data from the Oregon commercial fishing industry. The purpose of this chapter is to discuss possible extensions of the theoretical and empirical work presented. The following are suggested extensions of the research:

(1) Monitoring as a Choice Variable

In this thesis, the quantity of monitoring was a random variable, due to the nature of the postulated monitoring experiment. In other words, the thesis did not present the derivation of a demand function for monitoring services. A demand function would be derivable if monitoring was explicitly treated as a choice variable. One scenario where monitoring could be treated as a choice variable is a non-sequential monitoring experiment, where the firm chooses the optimal number of monitoring trials in advance. A model of this sort could be used to obtain implications regarding the factors influencing the market equilibrium price and quantity of monitoring services. However, the same qualitative result of an inverse relationship between monitoring expenditures and the variance of output would probably be obtained. Although not proven here, it can be shown that the optimal sample size rises with the variance of the parent distribution. This would lead to the result that the demand for monitoring services is a positive function of the variance of output;

(2) Substitutability Between Screening and Monitoring

Employee screening and monitoring were treated as independent activities in this thesis. However, one of the purposes of a screen is to filter out unproductive workers at the time of hiring, thus preventing costly on-the-job evaluation of such workers. Clearly, screening and monitoring are substitutes in the firm's production of information. In terms of the monitoring experiment presented in this thesis, screening and monitoring would be substitutes if, on average, resources expended on the formulation of the provisional estimate of expected marginal product lower the costs of monitoring. Therefore, an obvious extension of the two models would be the treatment of screening and monitoring as substitutes;

(3) A Longitudinal Theory of Monitoring

A limitation of both theoretical models is that they generate implications regarding decision making by firms at only one point in time - prior to production. Firms were depicted as formulating *expectations* of monitoring time and costs and to use these expectations to set initial wage and share offers. However, just because a firm expects that monitoring time will be longer the greater is the variability of marginal product, does not mean that monitoring time will actually be longer. It may turn out that monitoring time and costs are longer or shorter than expected. The theory does not explain the relationship between accrued wages and monitoring costs *actually* incurred. However, one important qualification needs to be made here. The theory of sequential sampling implies that the actual number of monitoring observations and the variance of output will be positively related *on average*, so for large samples of employees over a cross section of occupations, average actual monitoring time and output variability will be positively related. In other words, the theory can also be used to explain cross sectional differences in the outcomes (as op-

-posed to expectations of) monitoring experiments.

An extension of the theory would be to derive implications that can be tested on existing longitudinal data sets over turnover and tenure. For example, the models imply that waiting time to promotion, salary change or termination rise with the variability of output. While measures of these variables are not available, they are reflected in observable variables such as turnover and tenure. As a first approximation, an additional hypothesis is that turnover and tenure rise with the variability of output;

(4) Testing the Reformulated Screening Hypothesis

(A) An obvious extension of the work in Chapter 2 would be testing for an inverse relationship between earnings and employee output variability. This could perhaps be done through the estimation of an interoccupational or interpersonal earnings function with a variance of output term included.

(B) A second extension of the work from Chapter 2 would be more detailed specification of the signalling agent's choice problem to reflect the following: (1) the agent's accumulation of information about his own on-the-job peformance; (2) risk attitudes and uncertainty about productivity; (3) time costs of education;

(5) Alternative Specifications of Output Variability

In both theoretical models, each employee's output was assumed to be a normally distributed random variable. Although not shown here, the theory of sequential sampling implies the same relationships for other parent distributions. However, in many cases, it is not possible to specify the functional form of the parent distribution. Rather, the employee's output may only be definable in terms of some stochastic process. It would be interesting to examine the implications of a model based on a more sophisticated specification of employee output variability.

Other possible extensions are the following:

(6) A theory of contractual choice based on alternative regimes of sequential measurement costs,

(7) Monitoring with both output and market demand variability,

(8) A theory of equilibrium wages or shares where firms engage in joint contract enforcement - output measurement monitoring.

These suggested extensions all involve a more complicated specification of the firm's monitoring problem. Some of these specifications may require a departure from the sequential sampling framework adopted in the thesis. In addition, the feasibility of most of these extensions clearly depends on available data. It will be interesting to see how future longitudinal and cross sectional data sets allow for further exploration of the employee monitoring problem.

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] G. Becker, "Investment in Human Capital: A Theoretical Analysis," Journal of Political Economy, Oct., 1962, 70, 9-49.

[4] H.D. Brunk, Introduction to Mathematical Statistics. Toronto: Xerox College Publishing, 1975.

[5] S.N.S. Cheung, "Private Property Rights and Sharecropping," Journal of Political Economy, Nov.-Dec., 1968, 76, 1107-22.

[6] S.N.S. Cheung, "Transaction Costs, Risk Aversion, and the Choice of Contractual Arrangements," Journal of Law and Economics, April, 1969, 12, 23-42.

[7] P.C. Cox and T. Roseberry, "A Note on the Variance of the Distribution of Sample Number in Sequential Probability Ratio Tests," Technometrics, November, 1966, 8, 700-04.

[8] M. Degroot, Optimal Statistical Decisions, New York, N.Y: McGraw-Hill, 1970.

[9] M. Eswaran and A, Kotwal, "A Theory of Contractual Structure in Agriculture," American Economic Review June, 1985, 75, 352-67.

[10] M. Eswaran and A. Kotwal, "A Theory of Two-Tier Labor Markets in Agrarian Economies," American Economic Review, March, 1985, 75, 162-77.

[11] B. Holmstrom, "Moral Hazard and Observability," Bell Journal of Economics, Spring, 1979, 10, 74-91.

[12] B. Jovanovic, "Job Matching and the Theory of Turnover," Journal of Political Economy, Oct., 1979, 87, 972-90.

[13] R. Layard and G. Psacharopoulos, "The Screening Hypothesis and the Returns to Education," Journal of Political Economy, March-April, 1974, 82, 985-98.

[14] R.E.B. Lucas, "Sharing, Monitoring and Incentives: Marshallian Misallocation Reassessed," Journal of Political Economy, May-June, 1979, 87, 502-21.

[15] G. MacDonald, "A Market Equilibrium Theory of Job Assignment and Sequential Accumulation of Information," American Economic Review, Dec., 1982, 72, 1038-55.

[16] G. MacDonald, "Person-Specific Information in the Labor Market," Journal of Political Economy, June, 1980, 88, 578-97.

[17] P. Miller and P. Volker, "The Screening Hypothesis: An Application of the Wiles Test," Economic Inquiry, Sept. 1984, 25, 121-27.

[18] J. Mincer, Schooling, Experience and Earnings, New York, N.Y: National Bureau of Economic Research, 1972.

[19] 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.

[20] J.G. Riley, "Competitive Signalling," Journal of Economic Theory, April, 1975, 10, 175-86.

[21] J.G. Riley, "Informational Equilibrium," Econometrica, March, 1979, 47, 331-59.

[22] J.G. Riley, "Information, Screening and Human Capital," American Economic Review, May, 1976, 66, 254-60.

[23] J.G. Riley, "Testing the Educational Screening Hypothesis," Journal of Political Economy, Oct., 1979, 87, 227-52.

[24] S. Ross, P. Taubman and M. Wachter, "Learning by Observing and the Distribution of Wages," from: Sherwin Rosen, ed., Studies in Labor Markets, Chicago: University of Chicago Press, 1981.

[25] A.M. Spence, "Competitive and Optimal Responses to Signals: Analysis of Efficiency and Distribution," Journal of Economic Theory, March, 1974, 7, 296-332.

[26] A.M. Spence, "Job Market Signalling," Quarterly Journal of Economics, August , 1973, 87, 353-74.

[27] A.M. Spence, Market Signalling: Informational Transfer in Hiring and Related Screening Processes, Cambridge, Mass: Harvard University Press, 1974.

[28] J.E. Stiglitz, "Incentives and Risk Sharing in Sharecropping," Review of Economic Studies, April, 1974, 61, 219-56.

[29] J.E. Stiglitz, "Incentives, Risk and Information: Notes Toward a Theory of Hierarchy," Bell Journal of Economics, Autumn, 1975, 6, 552-79.

[30] J.E. Stiglitz, "The Theory of Screening, Education and the Distribution of Income," American Economic Review, June, 1975, 65, 283-300.

[31] J.G. Sutinen, "An Economic Theory of Share Contracting," Ph.D. Thesis, University of Washington, 1973.

[32] J.G. Sutinen, "Fishermens' Remuneration Systems and Implications for Fisheries Development," Scottish Journal of Political Economy, June, 1979, 26, 147-62.

[33] J.G. Sutinen, "The Rational Choice of Share Leasing and Implications for Efficiency," American Journal of Agricultural Economics, Nov., 1975, 57, 613-21.

[34] P. Taubman and T. Wales, "Higher Education, Mental Ability and Screening," Journal of Political Economy, Jan.-Feb., 1973, 81, 28-55.

[35] W. Viscuzi, "Employment Relationships with Joint Employer and Worker Experimentation," International Economic Review, June, 1983, 74, 313-22.

[36] A. Wald, Sequential Analysis, New York, N.Y: John Wiley and Sons, Inc., 1947.

[37] K. Wolpin, "Educational Screening," American Economic Review, Dec., 1977, 67, 949-58.

Appendix. The Expected Sample Size for a Sequential Employee Monitoring Test

Consider the following sequential test of two competing hypotheses that mean marginal product of an employee $E(q_j)$ from a normal distribution with known variance σ^2 is greater than or equal to a provisional estimate, $E\#(q_j | y_j)$. The hypothesis test is stated as the following:

(i) H_0: $E\#(q_j | y_j) < E(q_j) \quad \forall\ j=1,..,L$

(ii) H_1: $E\#(q_j | y_j) \geq E(q_j) \quad \forall\ j=1,..,L$

Assume the firm has chosen a probability of a of making a Type I error and a probability of b of making a Type II error. In addition, we assume that two values $E(q)_1$ and $E(q)_0$ have been chosen that guarantee to the firm that a and b are the maximum risks of Type I and II errors, respectively.

The length of monitoring time t* is a random variable with density f(t*). The general expression for the expected length of monitoring is given by the following:

(iii) $E(t^*) = \int t^* f(t^*)\,dt^*$

Wald [36] formally approximated (iii) for a sequential test that the mean is above or equal or below a predetermined value when the parent distribution is normal:

$$\text{(iv)}\quad E(t^*) = 2\left[\frac{D(u^*)\log(\frac{b}{1-a}) + (1-D(u^*))\log(\frac{1-b}{a})}{[E(q)_1{}^2 - E(q)_0{}^2] + 2[E(q)_1 - E(q)_0]E(q)_1}\right]\sigma^2 = \gamma\sigma^2$$

The expression D(u*) is the probability that the sequential ratio will lead to the acceptance of H_0 if u* is the true value of $E(q_j)$. The expression D(u*) is commonly known as the "operating characteristic function" for a sequential ratio test. Wald proved that for the preceding ratio test, D(u*) would take the following form:

$$(v)\ D(u^*) = \frac{(\frac{1-b}{a})^h - 1}{(\frac{1-b}{a})^{E(q)_1} - (\frac{b}{1-a})^h} \quad , \ h = \frac{E(q)_1 + E(q)_0 - 2u^*}{E(q)_1 - E(q)_0}$$

For a formal discussion of the derivation of (v), see Wald.