UMI Number: 9803437

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

A dissertation entitled

PERFORMANCE MEASUREMENT AND

COOPERATION IN TEAMS

submitted to the Graduate School of the
University of Wisconsin-Madison
in partial fulfillment of the requirements for the
degree of Doctor of Philosophy

by

Seung-Weon Yoo

Date of Final Oral Examination: September 23, 1997

Month & Year Degree to be awarded: **December,** 1997 **May** **August**

* *

Approval Signatures of Dissertation Readers: **Signature, Dean of Graduate School**

Ella Mae Matsumura Virginia S Hinshaw

PERFORMANCE MEASUREMENT AND COOPERATION IN TEAMS

by

Seung-Weon Yoo

A dissertation submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

(Business)

at the

UNIVERSITY OF WISCONSIN – MADISON

1997

ACKNOWLEDGMENTS

There are many individuals whose enormous contributions made this study possible. It is with great appreciation that I acknowledge their contributions. Special thanks to Dr. Ella Mae Matsumura, my major advisor, for her expert guidance and encouragement during all phases of my doctoral study in Madison. I sincerely appreciate the time and investment she has devoted to various aspects of this work.

I would like to express my deep gratitude to Dr. John Eichenseher and Dr. Donald Hausch. They have been consistently supportive, encouraging, and helpful, and their warmth and constant encouragement was a reassuring force through this endeavor. I would like to express my sincere gratitude to Dr. Yeon-Koo Che and Dr. Geoffrey Sprinkle, for their thoughtful reviews and helpful advice for this work.

Finally, I would like to thank my family. I am indebted to my parents, Gun-Ho Yoo and Nam-Yun Cho, for their unconditional love and invaluable support through my life. I also would like to express my gratitude to my parents-in-law for their support and encouragement. A very special thanks goes to my wife, Hae-Shin Hwang, for her constant love, support, encouragement throughout my academic years. A very special thanks also goes to my dear children, Brian Donghoon Yoo and Mina Jungmin Yoo, for providing me with great joy during this work.

PERFORMANCE MEASUREMENT AND COOPERATION IN TEAMS

Seung-Weon Yoo

Under the supervision of Associate Professor Ella Mae Matsumura
At the University of Wisconsin-Madison

The purpose of this dissertation is to examine the effects of performance measurement systems and incentive schemes on team performance. This dissertation focuses on uses of performance measures from an accounting perspective and examines the implications of the nature of relationships among agents and their tasks for designing economically optimal performance measurement systems. First, in the presence of externalities, I show that team-based information systems are better than individual information systems if the effect of the externality on agents' performance is significantly large. Furthermore, even under individual information systems, it is shown that the principal may decide to reduce the accuracy of information about individual performance because the negative effect of individual information systems increases as the accuracy of individual information systems increases. Second, I examine the effect of the relationship between cooperation activities and individual productive activities on performance measurement systems. The results show that the benefit of team-oriented performance measurement systems increases as the two types of activities are more *inseparable*. As the

two types of activities become *separable*, however, the agents can free-ride on the benefit of the cooperation activities under team-oriented performance measurement systems and, hence, the benefit of team-oriented performance measurement systems decreases. Finally, I show that team-oriented performance measurement systems can be used to motivate the agents to exercise appropriate problem-solving efforts if the errors associated with evaluation of problem-solving activities are significantly large. Specifically, team-oriented performance measurement systems reinforce the agents' incentives on problem-solving activities by supplementing the principal's imperfect evaluation of the agents' probiem-solving activities.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Chapter 1. General Introduction

Team-based organizational structures are frequently credited with contributing to corporate success in the current competitive business environment (e.g., Levine and Tyson, 1990; Dumain, 1994). Successful adoptions of team-based organizational structures are said to promote "cooperation" and "teamwork" among employees and to realize improvements in productivity, quality, and customer satisfaction. Furthermore, firms adopting potentially performance-improving new management concepts and manufacturing technologies, such as Total Quality Management (TQM), Flexible Manufacturing Systems (FMS), and lean production, are exhorted to transform their organizational structures from individual-oriented structures to team-based structures (e.g., Manz and Sims, 1993; Grant, Shani and Krishnan, 1994; Babson, 1995). Simple establishment of teams, however, may not be enough to realize expected "cooperation" and "teamwork". Research in the field of human resource management argues that successful transformations to team-based organizational structures are determined by several organizational features, such as interactions among team members and their tasks, interrelationships among various teams, management structures, and performance measurement processes (e.g., Hackman, 1990; Dumain, 1994; Miller and Butler, 1996). In case of transforming from individualistic organizational structures to team-based organizational structures, performance measurement systems are viewed as an especially important determinant of effectiveness of teams (Morhman, Cohen, and Morhman Jr., 1995). As Magee (1986, p. 254) points out, "modifications of the accounting (performance measurement) system and/or bonus calculations and/or organizational structure" are important issues in improving firms' overall performance.

Although team-oriented performance measurement systems are relatively well appreciated by practitioners and human resource management researchers, economic theories, including agency theory, have mostly focused on individual and competition-oriented performance measurement systems. For example, if employees' imperfect performance measures of the employees' unobservable efforts are positively correlated, under the optimal performance evaluation and reward system, each employee's rewards decrease as the other employee's performance increases (e.g., Holmstrom, 1982; Mookherjee, 1984). This competition-oriented performance measurement system is optimal for employers because it provides information on the common environmental effects on the employees' performance, and therefore, reduces the incentive problems arising from the unobservability of the employees' efforts. It is, however, argued that competition-oriented performance measurement systems may be counterproductive, especially if team members interact closely (e.g., Larson and LaFasto, 1989).

The purpose of this dissertation is to examine the effects on team performance of performance measurement systems and incentive schemes. This dissertation focuses on uses of employees' performance measures from an accounting perspective and examines the implications of the nature of relationships among employees and their tasks for designing economically optimal performance measurement systems. Specifically, the dissertation identifies the effects on employees' behavior and performance measurement systems of publicly observable performance signals (in chapter 3), cooperation opportunities (in chapter 4), and problem-solving activities (in chapter 5).

In chapter 3, I examine the implications of both decision-facilitating and decision-influencing roles of individual performance measures for the design of an optimal performance measurement system in a sequential production process using a principal-multiagent model. Information can serve a motivational or decision-influencing role because by evaluating employees' individual performance, an employer can motivate the employees to strive for the success of business. In many cases, however, information about an employee's performance is observed and used as input for decision making by the same or other employees, so that information serves a decision-facilitating role.

For example, consider sequentially interrelated production processes, in which the first employee supplies an intermediate product to the second employee, who in turn produces the final product using the intermediate product. In this case, it is common that the second employee's returns to effort increase as the first employee's performance increases. In the presence of this externality, information on the first employee's individual performance has both a decision-influencing effect on the first employee's decision making and a decision-facilitating effect on the second employee's decision making. Examining these dual roles of individual performance measures, I show that team-based performance measures (e.g., gainsharing or profit sharing) are better than individual performance measures for motivating the second employee if there exists a significantly large externality from the first employee's performance. Specifically, team-based performance measures are superior when the second employee can utilize information about the first employee's performance to maximize his own utility even though his decision is out of alignment with the firm's interests.[1] This decision-facilitating effect of the individual performance measure can increase the employer's expected costs of inducing the employee's desirable effort if the employer cannot penalize the employees' poor performance sufficiently due to employees' limited liability. Since the employer can be worse off by revealing information in this case, the employer chooses not to measure individual performance and focuses on the employees' overall performance as a team. Even under an individual information system, the employer may decide to reduce the accuracy of the individual information system to reduce the negative effect of individual performance measurement because the negative effect of the individual information system increases as the accuracy of the individual information system increases.

In chapter 4, I examine the effects of the relationships between cooperation activities and individual productive activities on performance measurement systems using a principal-multiagent model. The cooperation activity is characterized as a task which improves the productivity of the individual productive activities if all interacting employees are cooperative. For example, consider a product designer and a salesperson whose performance measures are affected by some common environmental factors. If both employees are cooperative, the salesperson will provide information about target customers' characteristics to the designer, and the designer will develop a product design

---

[1] Christensen (1982) shows with a numerical example that acquiring pre-decision public information induces the agents to use it for their decision, which may make it more expensive for the principal to enforce the preferred action choice.

which appeals to the target customers. In this case, their cooperation results in a better product design and greater customer acceptance. The benefits of cooperative activities, however, cannot be realized either if the salesperson decides not to provide information or if the designer decides not to incorporate the salesperson's information into the product design.

The results in chapter 4 show that the relationship between the cooperation activities and the individual productive activities determines the effectiveness of team-oriented performance measurement systems. The relationship between the cooperation activities and the productive activity can be defined as "*separable*" if the benefit of the employees' simultaneous cooperation can be realized without additional productive effort. For example, the designer can benefit from the salesperson's cooperation regardless of the salesperson's sales activity. Conversely, the relationship is defined as "*inseparable*" if the benefit of the employees' simultaneous cooperation is realized only with additional productive efforts. For example, the benefits of the designer's cooperation cannot be realized if he decides not to concentrate on better designs.

In chapter 4, I show that the benefits of a team-oriented performance measurement systems increase as the two types of activities are more inseparable. In the inseparable case, motivating the employees to cooperate reinforces the employees' incentives on productive activities since the benefits of cooperation cannot be realized without desired productive activities. In this case, team-oriented performance measurement systems are beneficial since they explicitly direct the employees' attention to cooperation. As the two types of activities become separable, the employees can free-ride on the benefit of the cooperation activities under team-oriented performance measurement systems whereas competition-oriented performance measurement systems enable the employer to measure the effects of the two types of activities separately, and hence filter it out from employees' wages. Therefore, competition-oriented performance measurement systems are beneficial for the employer as two types of activities become separable. Furthermore, the team-oriented performance measurement system is optimal if the effect of the cooperation activity on the productive activities is significant. Otherwise, the benefits of the competition-oriented performance measurement system in identifying the common environmental effects dominate the benefits of the team-oriented performance measurement system in inducing desired cooperation.

In chapter 5, I examine the effects of the nature of tasks on performance measurement systems. Specifically, I examine the situations where (i) an employee's effort affects both his and the other employee's performance in sequential production and (ii) both employees are engaged in problem-solving activities. First, I show that the form of an employee's optimal incentive contract depends on the effect of the employee's effort on performance measures, especially if performance measures signal both his and the other employee's performance. Using a similar characterization of the production process as in chapter 3, the results show that the first employee's reward increases as the second employee's performance increases, as well as his own performance increases (i.e., cooperation-oriented performance evaluation). The second employee's reward, however, increases as his own performance increases, but decreases as the first employee's performance increases (i.e., competition-oriented performance evaluation) even though no common environmental effects are associated with the employees' tasks. Unlike the literature examining the effects of a common environment (e.g., Holmstrom, 1982; Mookherjee, 1984), I show that a competition-oriented performance measurement system is used for the second employee's performance evaluation to distinguish between the second employee's contribution and the first employee's contribution to the outcome of the second task.

The second model in chapter 5 examines the effects of employees' problem-solving activities on performance measurement systems. I examine the situation under which two employees are engaged in a problem-solving activity and its result can improve the outcomes of their production tasks. Furthermore, it is assumed that the employer can subjectively evaluate the effectiveness of the outcomes of the problem-solving task on production. In this case, if the employer can accurately measure the effectiveness, the benefits of competition-oriented performance evaluation outweigh the benefits of team-oriented performance evaluation. Team-oriented performance measurement systems, however, become beneficial for motivating the employees to exercise proper problem-solving efforts if the errors associated with the principal's subjective assessment are significantly large. This is because team-oriented performance measurement systems reinforce the employees' incentives on problem-solving activities by supplementing the employer's imperfect evaluation of the employees' problem-solving activities.

Several articles are closely related to this research. Holmstrom and Milgrom (1990), Itoh (1991, 1992, 1993), Ramakrishnan and Thakor (1992), and Hemmer (1995) provide some explanations of the benefits of team-oriented performance measurement systems. Holmstrom and Milgrom (1990), Itoh (1991) and Ramakrishnan and Thakor (1992) show that full side-contracting can be optimal if (i) employees can monitor each other's efforts and (ii) the effects of common environmental factors are relatively small. Since the employees' monitoring ability provides an opportunity for risk sharing, the employer can be better off by delegating effort choices. Although mutual monitoring and risk sharing are important factors determining the benefits of teams, this dissertation shows that team-oriented performance measurement systems can be beneficial even without mutual monitoring and risk sharing opportunities. In fact, it is shown that the characteristics of relationships among the employees and their tasks can lead to the desirability of team-oriented performance measurement systems.

Itoh (1991, 1992) and Hemmer (1995) model the possibility of technological interactions among employees and examine their effects on incentive contracts. Itoh (1991) examines the possibility of an employee's "helping" effort and shows that positive helping effort (defined as teamwork) and team-oriented performance measurement systems are optimal for the employer when there is a complementarity relation between helping effort and own effort. While Itoh (1991) examines the case that each employee can independently provide the other employee with helping effort, I model a synergy effect of *joint* cooperation and the effects of the relationship between the cooperation activity and the productive activity on the incentive contract. The results show that the relationship between the cooperation activities and the productive activities is an important determinant of the optimal performance measurement system. Furthermore, Itoh's (1991, 1992) model can be viewed as a special case in which the employer cannot assess the effectiveness of problem-solving efforts and an employee's problem-solving effort improves the outcome of the other employee's task but does not improve the outcome of his task. Finally, Hemmer (1995) examines an alternative case in which team-based evaluation is inevitable. Although he models a sequential production process, his model is restricted to the case in which the quality of the intermediate product is unobservable, and hence only one performance measure (i.e., a team performance measure) is available given multiple tasks.

The following chapter reviews the literature regarding team structures, the effectiveness of teams, and performance measurement systems. Chapter 3 examines the effects of individual information systems on employees' incentives. Chapter 4 determines the effects of the relationships between cooperative activities and individual productive activities, and chapter 5 examines the effects of the nature of tasks on performance measurement systems. Chapter 6 provides concluding remarks.

Chapter 2. Literature Review

2.1 A Definition of "Team"

2.1.1 Definition

In the past decade, the use of teams in organizations has increased dramatically. This increase reflects changes in the competitive environment of many organizations. Though the concept has attained a degree of popularity with many organizations and researchers, there exist various definitions of "team." For example, Marschak and Radner (1972), in one of the earlier attempts to establish a theory of teams, define "team" as an organization in which each member has only common interests but her/his decision is based on different information. Since the team members are assumed to share common goals and prior beliefs, Marschak and Radner's model does not address possible motivational problems in a team. The team problem in their model is to design a team information structure to maximize the expected utility which is the common goal for the team members, taking account of information costs. Others use "team" to describe a group of people each of whom takes charge of a part of the team's performance but does not share common goals with the other team members. Team members are assumed to have different interests and, therefore, their decisions and actions are motivated to maximize their expected utility, not the team's performance. The team problem examined under this definition is to design an incentive contract to motivate team members to take desired actions when their actions cannot be observed. Since it is assumed that their decisions and actions cannot be observed and contracted upon, team members are evaluated based on indirect performance measures: either individual performance measures (for example, Holmstrom, 1982; Sappington and Demski, 1983; Mookherjee, 1984), or a single team performance measure (for example, Itoh, 1993; Hemmer, 1995; Arya, Fellingham, and Glover, 1997).

A useful definition that captures the essence of a "team" as used in this dissertation is provided by Mohrman, Cohen, and Mohrman Jr. (1995, p. 39): "A team is a group of individuals who work together to produce products or deliver services for which they are mutually accountable." Although this definition is somewhat broad, it highlights one important characteristic of a team: mutual accountability. Each team member interacts with other team members not only to develop her/his goals but also to achieve these goals. Lack of mutual accountability for their performance can prevent the achievement of the goals set by team members.[2] For example, a leading financial service company experiencing competitive problems developed a credible strategy to regain its competitive position (Katzenbach and Smith, 1993). The company's Executive Committee, however, failed to overcome individualism and remained accountable only for individual performance. Even though each member of the Executive Committee was competent in her/his area, the committee did not perform as a team and, therefore, failed to adopt the competitive strategy set for the company.

The team problem examined in this dissertation is a motivational problem (i.e., moral hazard) when team members' actions are unobservable. Specifically, this

---

[2] The implications of mutual accountability for designing performance measurement systems are provided in section 2.2.

dissertation examines the interrelationships between mutually-accountable performance measurement systems and team members' incentives. Therefore, the "team" referred to in this dissertation is not the same as the "team" in Marschak and Radner's model. Furthermore, a group of people supplying input for a production process (as in Holmstrom, 1982) is not classified as a "team" unless team members are mutually accountable for one or more performance measure(s). In this dissertation, "teams" are defined as a group of people who supply input for a production process and who are mutually accountable for one or more performance goals.

2.1.2 Types of teams

Within the broad definition of "team," it is useful to identify types of teams and characteristics of each type. Three basic types of teams commonly identified in the literature are: (1) work teams, (2) problem-solving teams, and (3) management teams (Larson and LaFasto, 1989; Dumain, 1994; McGrath and Hollingshead, 1994; Mohrman, Cohen, and Mohrman Jr., 1995).[3]

Work teams perform the work that results in the design and delivery of services or products. Following a well-defined plan, they perform day-to-day work, and tend to be permanent. If a work team is allowed to make decisions about the day-to-day work pace and execute actions autonomously to achieve its specific goals, it is described as a "self-managed" or "high-performance" team. Examples of work teams are production teams,

---

[3] It is reported that about two-thirds of American firms use work-teams and 91% of American firms use problem-solving teams (Dumain, 1994).

new product development teams, engineering teams, and sales and service teams. To be successful, work teams should have a high degree of team member commitment and a clear set of role and performance standards (Larson and LaFasto, 1989).

Problem-solving teams intend to identify and solve workplace problems. They have a specific mission and tend to be temporary, disbanding after they find a way to solve particular problems. Examples of problem-solving teams are task forces and project teams. Since problem-solving teams are asked to find a way to resolve workplace problems, team members must rely heavily on each other's specialties, suggestions, and creativity. Moreover, team members must develop a sense of "trust" in their fellow team members (Larson and LaFasto, 1989) because of the nature of their team. For example, consider a team of a marketing manager and a production manager charged with identifying reasons for and finding solutions to poor customer acceptance of a product. The marketing manager can easily blame the production manager for poor quality and, likewise, the production manager can blame the marketing manager for inappropriate marketing strategies. Unless team members overcome their attachments to their permanent function and build trust, it is unlikely that they will quickly succeed in finding ways to improve customer acceptance.

Finally, ***management teams*** are responsible for coordinating the activities of independent teams. Such teams consist of managers from various functional areas, such as design, production, and sales, and provide direction to independent teams to achieve the organization's goals. The Executive Committee in the previous section is an example of a management team. Although the authority of management teams comes from their formal hierarchical position, their success depends on their ability to identify the needs of independent teams and coordinate those needs toward the organization's ultimate goals (Mohrman, Cohen, and Mohrman Jr., 1995).

2.2 Effectiveness of Teams and Performance Measurement

There are many examples of successful implementation of team-oriented organizational designs. Service firms such as Federal Express and IDS have increased productivity up to 40% by adopting self-managed work teams (Dumain, 1994). AlliedSignal Aerospace reported an 11% increase in their aerospace revenue from implementing a team-based approach in the marketing area (*Wall Street Journal*, Aug. 26, 1996). Motorola, relying heavily on teams, succeeded in surpassing its Japanese competitors in cellular-phone markets by producing the world's lightest, smallest, and highest-quality products (Katzenbach and Smith, 1993). A team-oriented approach at Lake Superior Paper Company resulted in the most successful start-up in the history of the paper industry by delivering quality and productivity (Manz and Newstrom, 1990). It is, however, a well-known fact that team-oriented organizational structures are not always successful. As illustrated by the Executive Committee case in the previous section, a team-oriented approach may not improve the organization's performance and sometimes may increase interpersonal conflicts among team members. Therefore, it is important to identify the sources of effectiveness in teams and the management characteristics of successful team-oriented practices.

The key to team success in the current competitive environment is "synergy effects" or "cooperative performance increases." Katzenbach and Smith (1993, p. 18) summarize the sources of such synergy effects as the following:

> First, [teams] bring together complementary skills and experiences that, by definition, exceed those of any individual on the team ... Second, ... teams establish communications ... [that make them] flexible and responsive to changing events and demands ... Third, teams provides a unique social dimension that enhances the economic and administrative aspects of work [such as trust and confidence] ... Finally, teams have more fun ... [which] is integral to their performance.

It is noteworthy that "complementary skills" is a critical factor for an effective team.[4] As recognized by Alchian and Demsetz (1972), a synergy which exists when final outputs of team production are greater than the sum of individual production is an important determinant of an effective team.[5] For example, Cheney, Sims, and Manz (1993) discuss the success of total quality management teams at Texas Instruments Malaysia. Quality improvement teams at Texas Instruments Malaysia consist of professionals with complementary skills and knowledge from different departments. These cross-functional teams not only succeed in solving problems at hand, but also eliminate interdepartmental barriers, thereby creating an atmosphere conducive to the successful adoption of quality

---

[4] For example, Katzenbach and Smith (1993, p. 45) define a team as "a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable". They categorize these complementary skills as follows: (1) diverse technical or functional expertise, (2) effective problem-solving and decision-making skills, and (3) interpersonal skills, including communication.

[5] Alchian and Demsetz (1972, p. 779) define team production as "production in which (1) several types of resources are used, (2) the production is not a sum of separable outputs of each cooperating resource, [and] (3) not all resources used in team production belong to one person".

circles. Ultimately, Texas Instruments Malaysia succeeded in saving $50 million in 10 years due to quality improvements and the reduction of product cycle time by half. This successful implementation story illustrates how complementary skills among functionally different team members can contribute toward effective achievement of team performance goals.

To realize these synergies, researchers suggest implementing team-oriented organizational structures. A related issue is the development of reward systems that expand traditional individual-oriented performance measurement and reward systems (Ittner and Larcker, 1994; Johnson, 1992) to performance measurement systems that can provide both individual motivation and team-oriented incentives. Specifically, to promote successful teams, it is argued that performance measurement systems under team-oriented approaches should focus on mutual accountability to reward both team achievement and individual contributions without making team members compete with each other (Larson and LaFasto, 1989; Morhman, Cohen, and Morhman Jr. 1995).

Morhman, Cohen, and Morhman Jr. (1995) suggest several ways to accomplish this challenging task. First, employers can modify the individual-oriented performance system to accommodate a team-oriented organizational structure. For example, while maintaining individual performance measurement, employers can minimize the competitive features of a reward system and tie together the rewards of team members by using joint performance measurement. That is, each team member is rewarded not only for her/his own performance, but also for the other team members' performance. The second approach is to identify a specific "team" performance measure in addition to individual measures, and to reward a bonus for "team" performance. Finally, employers can initiate "gainsharing" and "profit sharing" to direct team members toward the improvement of the firms' overall performance.[6] These practices are not mutually exclusive, but can all be used together. These practices are important because they motivate and tie each team member's performance to the teams' performance.

A major obstacle to successfully implementing team-oriented performance measurement systems based on mutual accountability is opportunistic behavior (e.g., free-riding).[7] This obstacle accounts for the relatively few theoretical supports for team-oriented organizational approaches until recently.[8] In binding each team member's reward not only to individual success but also to team success, each team member receives a reward for other team members' efforts as well as her/his own effort. Such a reward scheme may be effective in inducing cooperation if each member is committed to the team's success, but may, alternatively, provide incentives for each team member to free-

---

[6] Gainsharing and profit sharing are reward systems which allow everyone in an organization to share in the economic value of the organization's performance (Morhman, Cohen, and Morhman Jr. 1995).

[7] Another obstacle suggested by some researchers and practitioners is "unfairness." For example, Morhman, Cohen, and Morhman Jr. (1995, p. 232) argue that "employees are reluctant to give up their traditional sources of self-esteem and feelings of individual contribution and sense of fair treatment. It feels wrong that they should be rewarded for what the group accomplishes, especially if the team is held back because of weak individual performance from others or if the team succeeds because of their own extraordinary performance."

[8] Recently, some economists have tried to provide theoretical explanations for team-oriented approaches. See Holmstrom and Milgrom (1990); Itoh (1991, 1992, and 1993); Ramakrishnan and Thakor (1991); Arya, Fellingham, and Glover (1997); and Che and Yoo (1997). These papers are discussed in the next section.

ride on the other team members' effort without exercising her/his due effort. As a result, team-oriented approaches may produce outcomes worse than those found in an individualistic reward system. Specifically, motivating each member's individual effort, not to mention cooperation, becomes costly for employers because of the opportunities for free-riding if team-oriented approaches are used. Furthermore, by focusing on team performance rather than individual performance, information systems under team-oriented approaches may not be able to produce requisite information for employers to evaluate their employees.

Although team-oriented performance measurement systems tend to promote employee free-riding, those systems are frequently evaluated as superior systems to individualistic performance measurement systems by practitioners, psychologists, and social scientists. This dissertation, using a principal-multiagent model, examines conditions under which mutually-accountable performance measures (i.e., team performance measures) are adapted to induce proper decision making and performance among employees. Specifically, this dissertation identifies the effects of information (in chapter 3) and relationships among employees and their tasks (in chapters 4 and 5) on team-oriented performance measurement systems.

2.3 Performance Measurement and Teams

2.3.1 Information system

In a single-period single-agent model, it is argued that the principal is never worse off, and is generally better off if she uses all available post-decision information for performance measurement. For example, Holmstrom (1979) shows that an additional (costless) post-decision performance signal y is valuable if an existing performance signal x is not a sufficient statistic of (x, y). Since these post-decision performance signals are used to evaluate the agent's unobservable efforts and motivate the agent, Demski and Feltham (1976) refer to this as information's decision-influencing role.

The decision-influencing role of post-decision information has formed the foundation for developments in theories of costly conditional monitoring policies (for example, Baiman and Demski, 1980; Dye, 1986; Kim and Suh, 1992) and of costly unconditional monitoring policies (for example, Baiman and Rajan, 1994). Assuming the hyperbolic-absolute-risk-aversion (HARA) family utility function, Baiman and Demski (1980) examine the principal's choice of the probability of variance investigation contingent upon the agent's observed performance.[9] They show that the optimal monitoring system is either a lower-tailed or upper-tailed "bang-bang" investigation policy. That is, additional information is acquired if output (costless information) falls below or rises above some critical level. Dye (1986) also shows that a lower-tailed monitoring policy is optimal if the available monitoring system is costly but perfect. If the monitoring system is not perfect, the policy is optimal given additional assumptions on the utility function and the monitoring system. Kim and Suh (1992) examine the principal's choice

---

[9] If an agent's utility function $F(z)$ is a member of the HARA family, $F(z) = [1/(q-1)][p+qz]^{[1-(1/q)]}$, where p and q are parameters and z is the agent's compensation. This class includes power, exponential, and logarithm utility functions and, hence, includes utility functions with increasing, decreasing, or constant absolute or relative risk-aversion (Baiman and Demski, 1980; Young, 1986; Baiman and Rajan, 1994). Young (1986) examines conditions under which Baiman and Demski's (1980) results hold without assuming HARA utility functions.

of the level of monitoring investment, not the probability of variance investigation. They show that the optimal level of monitoring investment depends on the monitoring technology. Monitoring investment decreases in the observed performance if the marginal precision of the monitoring system increases as monitoring investment increases ("concave monitoring technology"). If the marginal precision of the monitoring system is constant ("linear monitoring technology"), however, monitoring investment is bang-bang in nature. That is, the principal invests all or never invests in the monitoring system depending on the agent's performance.

While the above research on conditional monitoring policies assumes that the principal has a primary costless information system and examines the optimal design of a costly additional information system, Baiman and Rajan (1994) examine the optimal design of primary costly information systems without a costlessly available signal. Restricting the agent's utility function to a subset of the HARA family, they show that the optimal costly information system is designed to make the probability of the Type I error associated with the agent's desirable behavior smaller than the probability of the Type II error associated with the agent's undesirable behavior. For example, under the optimal information system, the probability of reporting "shirking" given that the agent worked hard is less that the probability of reporting "hard-working" given that the agent shirked. This result identifies a situation in which it is optimal to motivate the agent by using the "carrot" rather than the "stick."

In addition to information's decision-influencing role, information may be provided to the agent before his decision making to improve his decision making. Demski and

Feltham (1976) refer to this use of pre-decision information as information's decision-facilitating role. Several papers examine the implications of information's decision-facilitating role on the design of information systems facing the agent's private information (for example, Baiman and Demski, 1980; Christensen, 1981; Baiman, May, and Mukherji, 1990) or public information (for example, Christensen, 1982). Baiman and Demski (1980) examine the value of the agent's private-and-perfect pre-decision information. They show that the agent's private pre-decision information is valuable only under the restrictive conditions and, furthermore, they can show only necessary conditions due to their model specifications.

Assuming the agent's limited liability, Baiman, May, and Mukherji (1990) model the agent's reporting decision about his private pre-decision information (i.e., the state realization). They show that the principal's wealth increases as a costless information system's ability to detect the agent's lying increases. Furthermore, they also find that the agent's wealth may increase in the ability of detecting lying because of the agent's limited liability. The principal pays the minimum wage set by the agent's limited liability under a unfavorable state and requires low performance. In contrast, under a favorable state, the principal pays "excess returns" above the minimum wage and requires higher performance. If the principal wants to increase the performance requirement under the unfavorable state in order to increase her wealth, the difference in the performance requirements decreases and it may be optimal to increase the agent's excess returns to provide proper incentives under the favorable state since the principal cannot lower the agent's wage below the minimum wage. In this case, as the costless information system's ability to detect the agent's lying increases, the agent's report about the state realization becomes believable and the principal's incentive to increase the agent's excess returns increases. Therefore, it is possible to have the situations where both the principal and the agent are strictly better off as the costless information system's ability to detect lying increases.

Christensen (1981) examines the situation in which the agent has private pre-decision information about the state realization and the principal required for the agent to report his private information. He shows that the principal is not always better off by supplying the agent with a "finer" information system.[10] Although the finer information system is desirable if the agent uses information for decision making, it is not desirable if the agent uses information for shirking behavior. If the agent uses information from the finer information system for shirking, the principal is better off by preventing the use of the agent's finer information system, if possible. Furthermore, Christensen (1982) shows with numerical examples that pre-decision public information (which is observable by both the principal and the agent) may induce the agent to use it for his shirking decision and, therefore, may make it more expensive for the principal to induce the preferred action choice.

In summary, research on the design of information systems shows that costless post-decision information is beneficial for the principal and even a costly information system is valuable depending on the situation, while pre-decision information may not be

---

[10] Marschak and Radner (1972, p. 53) define "*fineness*" such that "of two given information structures, η_1 and η_2, η_1 is *as fine as* η_2 if η_1 is a subpartition of η_2; that is, if every set in η_1 is contained in some set in η_2. (Thus η_1 tells us all that η_2 can tell, and possibly more besides.) If η_1 and η_2 are distinct, and η_1 is as fine as η_2, then we shall say that η_1 is *finer than* η_2."

beneficial even if information is costless and observed by both the principal and the agent.[11] It is, however, common that information has both the decision-influencing and decision-facilitating roles in a multiagent setting. For example, consider a sequential production process in which the outcome of an agent's task is used as an input for the other agent's task. In this situation, information about the outcome of the first agent's task is post-decision information for the first agent (i.e, decision-influencing feature), but pre-decision information for the other agent (i.e., decision-facilitating feature).

Chapter 3 in this dissertation examines the possible conflicting effects of the information's decision-influencing and decision-facilitating roles on agents' behavior by modeling several issues with respect to specialized production processes and their associated information systems. Specifically, I examine conditions under which performance measures based only on joint outcomes (team-performance based measures) can be superior to performance measures based on individual outcomes (individual performance measures) in specialized but interrelated production processes. For example,

---

[11] Sometime, post-decision information is not beneficial for the principal. For example, Cremer (1995) shows that additional post-decision information about the agent's ability makes it impossible for the principal to commit herself on a strong incentive contract which includes a credible threat to fire the agent given sub-par performance regardless of the agent's ability. If a signal from a post-decision information system reveals that the reason behind sub-par performance is not the agent's ability but environmental, then the principal clearly wants to rehire the agent in the next period to avoid the uncertainty associated with a new agent's ability. If the principal use this post-decision information system, she cannot commit herself to the "firing threat"although she may be benefited by information about the agent's ability. If the benefits of committing the "firing threat" is bigger than the benefits of detecting the agent's true ability, the principal commits herself not to use post-decision information by intentionally increasing the costs of producing post-decision information.

incentive contracts like gainsharing or profit-sharing focus on the team's overall performance, ignoring individual contribution. Chapter 3 provides reasons why team-oriented organizational approaches tend to ignore individual information and focus on the aggregated information about team performance.

2.3.2 Employee relationships

Researchers viewing firms as a group of interacting people working to achieve a goal have extensively examined the interrelationships among employees and associated incentive contracts. The researchers model various types of relationships between employees, and, consequently, recommend different types of teams and associated compensation schedules to motivate agents. Table 2-1 summarizes many types of employee relationships and team concepts that have been examined in the literature. The employee relationships examined in the literature can be categorized as follows: (1) common environmental factors, (2) mutual monitoring, and (3) synergies, including a helping task.

The first category, indirect relationships based on *common environmental factors*, involves a group of people who do not need direct interaction, but are subject to common business factors. They are called a "team" because an aggregated outcome of their efforts constitutes the outcome of a business unit. For example, consider two regional auto marketing managers who are responsible for New York and Southern California, respectively. While they need not interact due to locational difference, their performance is influenced by some common environmental factors, such as general economic conditions,

Table 2-1: "Team" Papers

A. Employee Relationships

Compensation forms Interrelations	Full side-contracting	Joint performance evaluation (cooperation)	Relative performance evaluation
(1) Common environmental shocks			Lazear & Rosen (1981) Holmstrom (1982) Green & Stokey (1983) Mookherjee (1984) Demski & Sappington (1984) Lazear (1989)
(2) Mutual monitoring	Holmstrom and Milgrom (1990) Ramakrishnan and Thakor (1992) Itoh (1992)	Che and Yoo (1997)	
(3) Synergies including a helping task		Itoh (1991) Itoh (1992) Hemmer (1995)	

Table 2-1: "Team" Papers
(continued)

B. Model Specifications of "Team" Papers

	Optimal sharing	Linear sharing†
Continuous effort/ continuous output	Holmstrom (1982) Nalebuff & Stiglitz (1983) Green & Stokey (1983) Lazear (1989)	Hemmer (1995) Itoh (1992) Holmstrom and Milgrom (1987, 1990, 1991) **Chapter 5 in this dissertation**
Continuous effort/ discrete output	Lazear & Rosen (1981) Itoh (1991, 1993) Ramakrishnan & Thakor (1991)	
Discrete effort/ discrete output	Arya, Fellingham, and Glover (1997) Che and Yoo (1997) **Chapters 3 and 4 in this dissertation**	

† Assume exponential utility function and multi-normal distribution.

competition from other car makers, management philosophy, etc. Since the two marketing managers' performance is affected by environmental factors, an organizational structure and compensation scheme are supposed to isolate and identify these factors.

The literature that examines this type of relationship often identifies conditions under which relative performance evaluation is recommended to motivate team members. Specifically, assuming that agents cannot observe the environmental shocks before choosing effort levels, Holmstrom (1982) analyzes the moral hazard problem in a firm which is defined as a group of individuals organized so that their productive inputs are related in terms of the stochastic dependency among the individual tasks. He shows that, under the optimal incentive contract, the principal pays each agent contingent on his performance relative to the others (i.e., relative performance evaluation) if an agent's performance measure x is not a sufficient statistic of (x, y), where y is the performance measures of the other agents.[12] If the performance measures of the agents are positively correlated to each other and satisfy the monotone likelihood ratio property, each agent's compensation decreases as another agent's performance increases since an agent's performance provides information about *common* environmental shocks affecting the other agents' states of nature. Other researchers, such as Lazear and Rosen (1980), Green and Stokey (1983), and Nalebuff and Stiglitz (1983), have studied relative performance evaluation in the context of the interrelationship based on common environmental factors.[13]

---

[12] Moohkerjee (1984) documents similar results.

[13] Lazear and Rosen (1980) show that an advantage of relative performance evaluation systems is that they can eliminate compensation variance caused by the
(continued...)

They show that relative performance evaluation schemes can dominate independent contracts (e.g., piece rates) when the underlying production uncertainties for agents are correlated. The above papers show that the advantages of relative performance evaluation schemes are decreasing agents' risk from common environmental shocks and reducing information asymmetry problems.

Throughout this dissertation, relative performance evaluation is defined as incentive schemes under which each agent's compensation decreases as another agent's performance increases.[14] For example, under relative performance evaluation, the New York marketing manager's compensation decreases as the Southern California marketing manager's performance increases. Furthermore, rank-order tournaments are considered the extreme form of relative performance evaluation.

Although relative performance evaluation may appeal to some employers, it is not exactly a team-oriented performance evaluation system. The fundamental mechanism

---

[13](...continued)
common exogenous factors among agents and encourage increased effort. Green and Stokey (1983) and Nalebuff and Stiglitz (1983) examine the situation in which agents observe environmental factors before choosing efforts (i.e., information asymmetry between a principal and agents). Green and Stokey (1983) argue that whereas tournaments reduce an agent's risk from the common uncertainty factors, they also increase the risk by relating an agent's rewards to other agents' idiosyncratic random factors. Therefore, they conclude that the relative advantage of tournaments depends on which effect dominates. Nalebuff and Stiglitz (1983) argue the important characteristic of relative performance evaluation schemes is their flexibility. That is, while the agents' expected rewards do not vary with changes in the common environmental factors, the agents' effort levels do. Therefore, relative performance evaluation schemes (typically tournaments) are able to flexibly adjust incentives in response to common changes in the environments.

[14] Itoh (1991, 1992) and Choi (1993) use similar characterizations of relative performance evaluation.

driving relative performance evaluation is competition among employees and, therefore, relative performance evaluation is not consistent with the notion of cooperative teams. As discussed in section 2.2, it is argued that team-oriented performance measurement systems emphasize team members' mutual accountability, not competition. Furthermore, research on relative performance evaluation tends to focus only on the indirect environmental relationship among agents since their models do not explicitly recognize a production setting or a direct interaction among agents. Because modern manufacturing processes require close interactions among agents, simple environmental relationships are not enough to explain today's team-oriented organizational structure.

The second category of employee relationships examined in several recent papers is *mutual monitoring* within a team. Holmstrom and Milgrom (1990), Itoh (1992, 1993), and Ramakrishnan and Thakor (1992) examine the possibility of full side-contracting. Full side-contracting means that agents are able to contract with each other based on commonly observable events, thereby inducing cooperation among the agents if the agents are able to observe each other's effort choices. If the principal and the agents share the same information, full side-contracting has no value for the principal (Holmstrom and Milgrom, 1990). In contrast, if the employees have information which cannot be observed and contracted upon by the principal, then the principal may be better off by contracting with the team as a whole and allowing the agents to contract with each other based on their private information. Since each team member can observe the other members' effort due to their close and frequent interactions, the possibility of effort monitoring constitutes team members' unique private information.[15] As a result, it can be beneficial for the principal to compensate a team as a whole and to allow team members to determine the specific tasks and compensation allocations among them without the principal's intervention. Holmstrom and Milgrom (1990), Itoh (1992, 1993) and Ramakrishnan and Thakor (1992) show that full side-contracting can be optimal if the agents can monitor each other's efforts and the effects of common environmental factors are relatively small. Since the agents' monitoring ability provides an opportunity for risk sharing among the agents, the principal can be better off by delegating effort choices. If the effects of common environmental factors are relatively large, however, then relative performance evaluation is better than full side-contracting. Furthermore, Itoh (1992, 1993) considers a situation where team performance measurement is inevitable, that is, where the outcomes of individual tasks are not observable to the principal while the total outcome is publicly observable. He shows that additional individual performance measures are not valuable for the principal when the agents side-contract, under the assumption that the production is technologically independent, the agents are identical, and the environmental factors are stochastically independent.

Arya, Fellingham, and Glover (1997) and Che and Yoo (1997) examine the effects of mutual monitoring in a multiperiod setting. Specifically, they note that continuous interactions among team members provide an opportunity to develop an implicit penalty scheme (e.g., peer pressure) for a free-rider. By assuming mutual monitoring and

[15] Another possibility of superior information is examined by Varian (1990). He shows that the principal can benefit from side-contracting if the employees share information about the state of nature which is not observable by the principal.

multiperiod interactions, Arya, Fellingham, and Glover (1997) show that a team-oriented incentive scheme is preferable to an individualistic incentive scheme. They assume only uncorrelated individual performance measures are available; consequently, there is no possibility of relative performance evaluation. Furthermore, they demonstrate that the principal can be better off by using two different compensation schemes for each period: strict team incentives for the first period and individual incentives for the second period. By allowing the agents to use individual incentives as a penalty scheme, the principal is able to use the team-oriented incentive scheme, under which the principal pays lower compensation and, hence, provides weaker incentive than the individual incentive scheme.

In contrast, Che and Yoo (1997) assume a common environmental shock and compare the benefits of a competitive incentive scheme (e.g., relative performance evaluation or tournaments) to a cooperative incentive scheme (e.g., joint performance measurement). Under joint performance measurement, an agent's compensation increases as another agent's performance increases. Che and Yoo (1997) examine conditions under which the benefits of agents' implicit penalty based on mutual monitoring can be realized. They show that there exists a cut-off value for measures of the degree of common environmental factor such that a team-oriented cooperative incentive contact is preferred to relative performance evaluation if and only if the degree of common environmental factor is lower than the threshold level. If the degree of common environmental factor is sufficiently low, the principal can enhance her wealth by making each agent accountable for the other agents' performance (i.e., team-oriented incentive contracts) since only team-oriented incentive contracts utilize the agents' monitoring ability and implicit penalty.

The third category of agent relationships examined in the literature is *technological synergies* among team members. Itoh (1991, 1992) examines the possibility of a "helping" effort to explain team-oriented task allocation and incentive contracts. In his model, each agent is assumed to be responsible for two tasks, "own effort" and "helping effort", and the tasks are assumed to be independent of each other. Each agent's helping effort is assumed to increase the productivity of the other agent's own effort. For example, consider a relationship between a computer designer and a quality controller. The product designer's main task is designing, but he can assist the quality controller by providing advice based on his knowledge about the design. Therefore, the computer designer's advice can be viewed as a helping effort which can save testing costs. Itoh (1991, 1992) shows that positive helping effort, which he defines as teamwork, is optimal to the principal when there is a complementarity relation between own effort and helping effort. That is, positive helping effort is desirable if an agent's increase in his helping effort increases the productivity of the other agent's own effort. In this case, the agent's compensation should be based on the performance measures of both tasks, and it should be increasing in both measures (i.e., joint performance evaluation) rather than decreasing in the other agent's performance measure as in relative performance evaluation. Teamwork is optimal even in the case of free-riding, with respect to helping effort, if the resulting decrease in an agent's own effort reduces the costs of own effort sufficiently.

Hemmer (1995) examines an alternative case in which team performance evaluation is inevitable. That is, only one performance measure is observable despite multiple tasks. Hemmer (1995) models a sequential production process and the effect of productivity on the organizational structure. He also assumes that the first agent's quality-enhancing effort has a cost-reducing effect on the second agent's task, or a technological synergy. He shows that the principal can induce the agents to increase quality-enhancing effort if: (1) it is possible to assign both tasks to both agents and (2) high productivity enables high volume with relatively lower quantity-enhancing effort. Although the sequential production process is an important characteristic of manufacturing processes, Hemmer's concept of team is limited to craftsmanship. Craftsmanship implicitly assumes all agents are able to perform all phases of the manufacturing process, counter to the notion of specialization which is an important characteristic of many modern manufacturing processes. Moreover, since all manufacturing tasks are performed by every agent, craftsmanship highlights interrelationships among tasks, but not interrelationships among agents. For example, Hemmer's (1995) model specifies an effect of the outcome of the first product on the second product in terms of quality, but there need not be any interaction between the two agents because each agent performs both tasks.

Although the above research on the effects of synergies illustrates a benefit of team-oriented performance evaluation, it is limited to synergies stemming from "helping" effort. Chapters 4 and 5 in this dissertation examine the effects of various synergies stemming from relationships among agents and their tasks on incentive contracts. Specifically, I establish characteristics of performance measurement systems under which the benefits of agents' mutual cooperation (chapter 4) can be efficiently realized, and examine the effects of task relationships on performance measurement system (chapter 5). By examining the effects of the characteristics of relationships among agents and their tasks on team-oriented performance measurement systems, chapters 4 and 5 provide conditions under which team-oriented organizational approaches are successful in improving organizations' overall performance.

Chapter 3. Information Systems and Teams

3.1 Introduction

Recently, firms have been adopting new management concepts and manufacturing technologies such as Total Quality Management (TQM), Just-In-Time (JIT), and Flexible Manufacturing Systems (FMS) to improve their performance. Implementing these concepts and technologies often involves extensive use of teams. For example, TQM emphasizes horizontal structures (e.g., cross-functional teams) rather than vertical organization structure (Grant, Shani and Krishnan, 1994). Team-oriented approaches are suggested to encourage positive interaction among manufacturing production members who have closely-related specialties and are working toward a common goal. The team-oriented approach, however, is not always successfully nor extensively used. For example, a survey of FORTUNE 1,000 firms shows that 68% use self-managed teams; yet only 10% of the workers are in such teams (Dumaine, 1994). This result suggests that team-oriented organizational structures may be beneficial only in specific environments.[16]

The purpose of this chapter is to examine the economic benefits of team-oriented information systems in different manufacturing environments and in relationships among employees. One of the characteristics of team-oriented organizational approaches is that they tend to ignore individual information and focus on aggregated information about team performance. For example, incentive contracts like gainsharing or profit-sharing focus on

[16] Dumaine (1994) suggests that only the use of "the right team for the right job" can overcome the drawbacks of the team approach.

the team's overall performance, ignoring individual contributions (Mohrman, Cohen, and Mohrman Jr., 1995). Since optimal organization structures and information systems depend on business environments and relationships among employees, it is important to identify these relationships and examine the optimality of different types of information systems. Specifically, this chapter examines employee relationships based on specialized tasks and an externality.

It is argued that the principal is never worse off, and is in general better off if she uses all available information for employee' performance measurement, especially if information systems produce post-decision information (Holmstrom, 1979). The decision-influencing feature of post-decision information allows the principal to motivate employees more efficiently. In many cases, however, information about an employee's performance is observed and used by the same or other employees as pre-decision information. In the case of work teams, which consist of members with specialities, each member's performance affects the other members' productivity. For example, Abramis (1990, p. 39) reports that in "Datron" team, a semiconductor manufacturing team, members are "highly dependent on one another to accomplish the team's work; if one member falls behind in his or her work, others were unable to do theirs". Thus, there exists an externality between team members. High performance on a task is critical to the other tasks' success, even though each task can be performed only by a highly specialized member.[17] Therefore, information about an agent's individual performance is not only

---

[17] Another example is manufacturing "cells". The *Wall Street Journal* (Oct. 24, 1994) reports that many Japanese and U.S. companies implement these hybrid lines. For (continued...)

post-decision information for the agent, but pre-decision information for another agent. In this case, it is not always beneficial to have pre-decision information even if information is costless and publicly observable. For example, as Christensen (1982) shows with a numerical example, acquiring pre-decision public information enables the agents to use it for their decision, which may make it more expensive for the principal to enforce the preferred action choice.

This chapter examines both the decision-facilitating and decision-influencing roles of individual performance measures by modeling several issues with respect to specialized production processes and their associated information systems. Specifically, I examine conditions under which performance measures based on joint outcomes (team-performance based measures) can be superior to performance measures based on individual outcomes (individual performance measures) in specialized, but interrelated production processes. In the model of a principal and two agents, the externalities between the agents' performances are specified in terms of a probability structure. Also, the agents' limited liability is assumed to capture the principal's limited ability to penalize the agents in a manufacturing environment. By introducing the agents' adaptive behaviors following an individual performance report, I present specific conditions under which an imperfect individual-performance inspection system leads to inefficient results, given externality in the production processes and the agents' limited liability. First, it is shown that team-based

---

[17](...continued)
example, Sony forms a snail-shaped shop for four workers and makes them assemble an entire camera themselves. Sony reports 10% higher output on this experimental line than on a conventional one. Also, in a survey of 1,042 American plants, 34% report "moderate or extreme" success with assembly cells.

performance measures are better than individual performance measures for motivating an agent if: (1) the realization of the externality increases as the agent's effort increases, or (2) the realization of the externality decreases as the agent's effort increases and the effects of the agent on his performance decreases as the other agent's performance increases. In both cases, the agent utilizes information about the other agent's performance to decide his effort level. This decision-facilitating effect of the individual information increases the principal's expected costs of inducing the agent's desirable effort. If the principal cannot sufficiently penalize the agents' poor performance and individual information can be used for the agents' adaptive decision making, the principal can be worse off by revealing information. Furthermore, as the accuracy of the individual information system increases, the negative effect of the individual information system increases. If the principal can commit herself not to reveal individual information before the second agent makes an effort decision, individual performance measures are valuable. As such a commitment often is not possible under the most information systems, the principal may decide not to use individual performance measures or to delay inspection until all production processes are finished. At an extreme, instead of relying on in-house information systems, the principal may rely on markets to ascertain the agents' performance.

There are several articles which examine the implications of team-oriented information systems on performance measurement and incentives. Itoh (1992, 1993) considers a situation where team performance measurement is inevitable, that is, where the outcomes of individual tasks are not observable to the principal while the total outcome is publicly observable. He shows that additional individual performance measures are not valuable for the principal when the agents side-contracting, under the assumptions that the production is technologically independent, the agents are identical, and the environmental factors are stochastically independent. If the principal and the employees share the same information, full side-contracting has no value for the principal (Holmstrom and Milgrom, 1990). If the employees have private information which cannot be observed and contracted upon by the principal, however, the principal may be better off by allowing the employees to make a side-contract based on their private information. Since each team member can observe the other members' effort due to their close and frequent interactions, the possibility of effort monitoring constitutes team members' unique private information.[18] As a result, it can be beneficial for the principal to compensate a team as a whole and to allow team members to determine the specific tasks and compensation allocations among them without the principal's intervention.[19] Given Itoh's (1992, 1993) assumptions, he argues that side-contracting, which he defined as "delegated cooperation", is an efficient mechanism which eliminates collusion problems between the supervisor and the agents. While Itoh's (1992, 1993) conclusions are based on the assumptions of mutual monitoring

---

[18] Another possibility of superior information is examined by Varian (1990). He shows that the principal can benefit from side-contracting if the employees share information about the state of nature, which is not observable by the principal.

[19] Some papers examine the implications of mutual monitoring on incentive contracts. For example, Holmstrom and Milgrom (1990), Itoh (1991) and Ramakrishnan and Thakor (1992) show that full side-contracting can be optimal if (1) the agents can monitor each other's efforts and (2) the effects of common environmental factors are relatively small. Since the agents' monitoring ability provides an opportunity for risk sharing, the principal can be better off by delegating effort choices. If the effects of common environmental factors are relatively large, however, then RPE is better than full side-contracting.

and side-contracting, this chapter shows that team-oriented information systems can be better if there are externalities between the agents and the agents have limited liability.

Hemmer (1995) also examines the situation wherein quality cannot be measured internally and, consequently, the only performance measure is quantity. He models a sequential production process and the effect of productivity on the organizational structure. Also, he assumes the first agent's quality-enhancing effort has a cost-reducing effect on the second agent's task, in other words, technological synergies. Hemmer shows that the principal can induce higher quality-enhancing effort if it is possible to assign both tasks to both agents and if high productivity enables high volume with relatively lower quantity-enhancing effort. While his sequential production setting is similar to the model used in this paper, Hemmer assumes that quality is not measurable and, therefore, eliminates the possibility of quality-based information systems and the value of additional information.

Although it is not a team-related study, Cremer (1995) shows that additional information about employees' ability and performance makes it impossible for the principal to commit herself to a strong incentive contract: for example, the principal cannot threaten employees with termination given sub-par performance regardless of their efforts. If information reveals an employee is productive and the reason behind sub-par performance is environmental rather than less effort, then the principal clearly wants to rehire the employee in the next period to avoid the uncertainty associated with a new employee. By not using this efficient and costless information system, the principal commits herself to the "firing" threat and provides a stronger incentive to the employees. As in Cremer's (1995) model, this chapter incorporates the principal's limited ability to punish agents. This chapter, however, specifically addresses information systems on individual performance, which are not an issue in Cremer's (1995) paper. While his model considers the investigation of an agent's productivity, which is not known to either the principal or the agent, this chapter evaluates the value of information systems about individual performance on an agent's decision making.

The following section explains the model. Section 3.3 characterizes the individual information system and the team information system. Section 3.4 examines the optimality of team-oriented information systems. Extensions and a brief summary are provided in Section 3.5.

3.2 Model

This section examines a discrete model to study the effect of inspection on the second agent's behavior given workers' limited liability. The discrete model assumes an implicit relationship between agents through the probability of success. Table 3-1 summarizes the notation.

Suppose the following model of a production process. There are a principal and two agents, indexed i=1, 2. Each agent takes an unobservable action (i.e., effort), e_i. Effort levels can be high (h for agent 1 and H for agent 2) or low (ℓ for agent 1 and L for agent 2). As a result, agent i produces one unit of product i, which has quality level x_i. The first product is an intermediate good which has no market value, but is used to produce the second and valuable product. The quality of the intermediate product, x_1, is determined by e_1 together with a random state of nature ϵ_1 (i.e., $x_1 = x_1(e_1, \epsilon_1)$). The quality of the final

Table 3-1: Notation

x_1 = quality level of product 1.
x_g = *good*-quality product 1; x_b = *bad*-quality product 1.

x_2 = quality level of product 2.
x_G = *good*-quality product 2; x_B = *bad*-quality product 2.

$\pi(x_2)$ = profit from x_2.

$s_1(\cdot)$ = first agent's wage as a function of I_1 or x_2, or both.
$s_2(\cdot)$ = second agent's wage as a function of x_2 or both x_2 and I_1.
$U_i(\cdot)$ = agent *I*'s utility as a function of W_i and e_i.
$c_i(\cdot)$ = agent *I*'s disutility as a function of e_i.
EU_p = principal's expected utility.
EU_A^i = agent I's expected utility.

I = inspection outcome.
I_g = *good*-quality of x_1 suggested by the inspection system;
I_b = *bad*-quality of x_1 suggested by the inspection system.

e_1 = first agent's effort level.
e_h = *high* effort level by agent 1; e_ℓ = *low* effort level by agent 1.
e_2 = second agent's effort level.
e_H = *high* effort level by agent 2; e_L = *low* effort level by agent 2.

$\Delta_1 = c_1(e_h) - c_1(e_l)$.
$\Delta_2 = c_2(e_H) - c_1(e_L)$.

$p_h = prob(x_g : e_h)$; $1-p_h = prob(x_b : e_h)$.
$p_\ell = prob(x_g : e_\ell)$; $1-p_\ell = prob(x_b : e_\ell)$.

$q_{H,g} = prob(x_G : e_H, x_g)$; $1-q_{H,g} = prob(x_B: e_H, x_g)$.
$q_{H,b} = prob(x_G : e_H, x_b)$; $1-q_{H,b} = prob(x_B: e_H, x_b)$.
$q_{L,g} = prob(x_G : e_L, x_g)$; $1-q_{L,g} = prob(x_B: e_L, x_g)$.
$q_{L,b} = prob(x_G : e_L, x_b)$; $1-q_{L,b} = prob(x_B: e_L, x_b)$.

v_H = externality realized by the second agent's high effort level = $q_{H,g} / q_{H,b}$.
v_L = externality realized by the second agent's low effort level = $q_{L,g} / q_{L,b}$.

Table 3-1: Notation (continued)

θ_g = effectiveness of the second agent's effort given $x_g = q_{H,g} - q_{L,g}$.
θ_b = effectiveness of the second agent's effort given $x_b = q_{H,b} - q_{L,b}$.

$\alpha_h = prob(x_g : I_g, e_h) = p_h / [p_h+(1-\beta)(1-p_h)]$;
$1-\alpha_h = prob(x_b : I_g, e_h) = [(1-\beta)(1-p_h)] / [p_h+(1-\beta)(1-p_h)]$.
$\alpha_\ell = prob(x_g : I_g, e_\ell) = p_\ell / [p_\ell+(1-\beta)(1-p_\ell)]$;
$1-\alpha_\ell = prob(x_b : I_g, e_\ell) = [(1-\beta)(1-p_\ell)] / [p_\ell+(1-\beta)(1-p_\ell)]$.
$prob(x_b : I_b, e_h) = prob(x_b : I_b, e_\ell) = 1$;
$prob(x_g : I_b, e_h) = prob(x_g : I_b, e_\ell) = 0$.

$\beta = prob(I_b : x_b) = (\alpha_h-p_h) / \alpha_h(1-p_h) = (\alpha_\ell-p_\ell) / \alpha_\ell(1-p_\ell)$;
$1-\beta = prob(I_g : x_b) = p_h(1-\alpha_h) / \alpha_h(1-p_h) = p_\ell(1-\alpha_\ell) / \alpha_\ell(1-p_\ell)$.
$prob(I_g : x_g) = 1$;
$prob(I_b : x_g) = 0$.

product, x_2, is determined by e_2, ϵ_2, and x_1 [i.e., $x_2 = x_2(x_1(e_1,\epsilon_1), e_2, \epsilon_2)$]. The principal sells the second product in the market, which can correctly determine the quality.

The quality level of product *i* can be good (x_g for product 1 and x_G for product 2) or bad (x_b for product 1 and x_B for product 2). The probability that the first product has good quality given the first agent's high (low) effort level is p_h (p_l). The probability of a good-quality second product given the second agent's high effort level and a good-quality (bad-quality) x_1 is $q_{H,g}$ ($q_{H,b}$). Similarly, the probability of a good-quality second product given the second agent's low effort level and the good quality (bad quality) of x_1 is $q_{L,g}$ ($q_{L,b}$). It is assumed that a good-quality second product is achievable even if the quality of the first product is not good (i.e., $q_{H,b} > 0$ and $q_{L,b} > 0$). A bad-quality first product is undesirable only because it decreases the probability of a good-quality second product.[20] Using the above notation, externalities are defined below:

---

[20] This can be explained in terms of the effects of the quality of the intermediate product on the second agent's effort. For example, a good-quality intermediate product can decrease the second agent's effort on his task while a bad-quality intermediate product cannot. Since I assume only two levels of effort, these externalities are assumed to affect the probability. Another example of this relationship is a production-and-rework sequence. After the first agent produces a product, the second agent checks the quality and corrects any problems with the product. In this production sequence, the second agent can deliver a good-quality final product even though the quality of the first product is not good. Furthermore, there exists an externality of the first agent's effort level. If the first agent produces a large number of bad-quality products, the second agent may not be able to rework all the products due to time and resource limitations. In contrast, if there are only a few bad-quality first products, the second agent can fix them all. Hence, the first agent's effort will decrease the number of bad-quality first products.

Definition (Externality): The externality realized by the second agent's high effort level, v_H, is defined as $q_{H,g}/q_{H,b}$. Similarly, the externality realized by the second agent's low effort level, v_L, is defined as $q_{L,g}/q_{L,b}$.

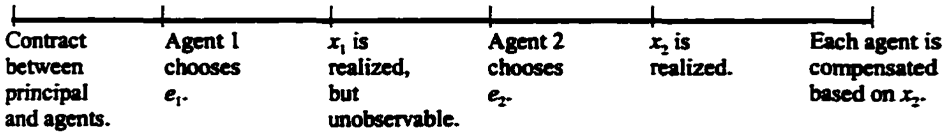
Since it is assumed that $q_{H,g} \geq q_{H,b}$ and $q_{L,g} \geq q_{L,b}$, both externalities are positive: $v_H \geq 1$ and $v_L \geq 1$. If $v_H = v_L = 1$, then there are no externalities associated with the quality of the intermediate product. If $v_H > 1$ or $v_L > 1$, then a positive externality is associated with the quality of the intermediate product. Furthermore, the effectiveness of the second agent's effort on the quality of the final product is defined as follows:

Definition (Effort Effectiveness): The effectiveness of the second agent's effort on the quality of the final product given a good-quality intermediate product is defined as $\theta_g \equiv q_{H,g} - q_{L,g}$. Similarly, the effectiveness of the second agent's effort on the quality of the final product given a bad-quality intermediate product is defined as $\theta_b \equiv q_{H,b} - q_{L,b}$.

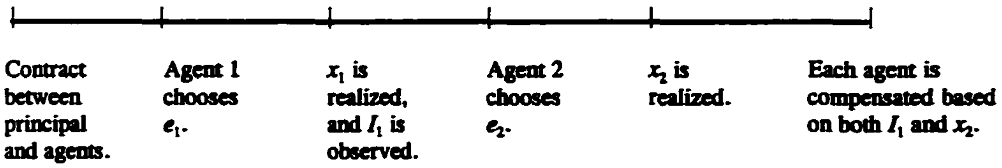
The quality of the final product, x_2, is assumed to be observable by market participants, the principal, and the two agents. In contrast, it is assumed that the quality of the intermediate product, x_1, is not directly observable, but is testable using an inspection system. The available inspection system is assumed to correctly detect the good-quality x_1 with a probability of 1. The system, however, correctly detects the bad-quality x_1 with a

Figure 3-1: Sequence of Events

A. Case 1: Team Information System



B. Case 2: Individual Information System



probability of $\beta \in [0, 1]$.[21] The inspection report of good (bad) quality is denoted as I_g (I_b). It is assumed that an inspection report (I_1) is observable to the principal and the two agents immediately after the first agent completes his job. Therefore, the second agent can use this inspection report to adjust his effort. Figure 3-1 specifies the sequence of events.

[21] Therefore, the available inspection system is perfect with respect to the good-quality x_1, but is imperfect with respect to the bad-quality x_1. This characteristic is not uncommon. If an investigator finds problems with a product, the product is bad. No evidence of problems does not guarantee a good-quality x_1, however, because the investigator might fail to detect the problems existing in the product.

The principal and the two agents are assumed to be risk neutral. The principal's utility (EU_p) is defined over the profit from x_2 ($\pi(x_2)$) and compensation (s_i); that is, $EU_p(\pi(x_2), s_1, s_2) = E(\pi(x_2) - s_1 - s_2)$. Each agent's utility function (EU_A^i, i=1,2) is defined over compensation and effort; that is, $EU_A^i(s_i, e_i) = U_i(s_i) - c_i(e_i)$, with $c_i' \geq 0$ and $c_i'' \geq 0$. Risk-neutrality of the agents implies that $U_i(s_i) = s_i$. Also, it is assumed that there is a limit to the maximum penalty that each agent can bear.[22] Without loss of generality, I assume that the limit is $c_i(e_i)$.[23] Therefore, the principal's problem is the following:

$$\max_{s_i,\, e_i} \quad E(\pi(x_2) - s_1 - s_2)$$

subject to

$$E(s_1) - c_1(e_1) \geq 0;$$

$$E(s_2) - c_2(e_2) \geq 0;$$

$$e_1 \in \text{argmax } E(s_1) - c_1(e_1'), \text{ where } e_1' \in \{e_h, e_l\};$$

$$e_2 \in \text{argmax } E(s_2) - c_2(e_2'), \text{ where } e_2' \in \{e_H, e_L\};$$

$$s_1 - c_1(e_1) \geq 0;$$

$$s_2 - c_2(e_2) \geq 0.$$

---

[22] Limited liability is not uncommon in practice. For example, in many circumstances, the maximum penalty a principal can impose on an agent is to simply fire the agent. Limited liability is supported and discussed by several researchers (for example, Sappington, 1983 and 1991; Milgrom, 1988; Baiman, May, and Mukherji, 1990; and Cremer, 1995).

[23] This assumption implies that the principal guarantees zero utility compensating the agents' disutilities associated with work. Although this assumption intends to highlight a positive base salary, the results remain the same qualitatively even though the limit is normalized to zero. In chapter 4, I assume the zero limit to simplify the analysis.

The first two constraints in the principal's problem represent the two agents' individual rationality constraints, whereas the second two constraints represent their incentive compatibility constraints. The final two constraints are the two agents' limited liability constraints.[24]

3.3 Team Information System and Individual Information System

In this section, optimal solutions assuming the team information system and the individual information system are derived and discussed. Since a purpose of this model is to compare the information schemes, I restrict my analysis to the case in which the principal wants to induce a high effort level from both agents.[25]

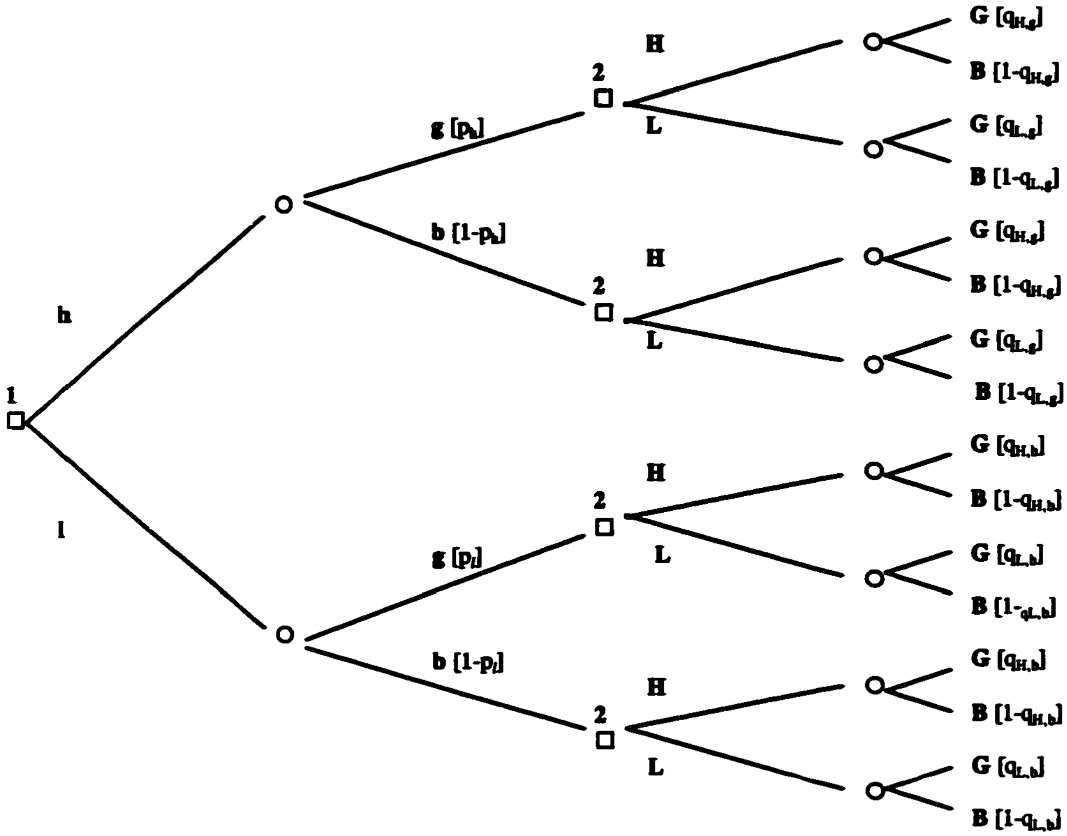
I examine the benefits of the two information systems: the team information system and the individual information system. The team-based information system represents the performance evaluation scheme based on the outcome of both agents' combined performance. In this case, the principal does not utilize the individualistic inspection system, but uses only the realized outcome of the final product, representing the team's production. The decision tree under the team information system is in Figure 3-2. In contrast, under the individual information system, the principal utilizes the inspection report and the outcome of the final product to compensate each agent. Therefore, both

---

[24] The individual rationality constraints are not binding because of the binding limited liability constraints. The binding incentive constraints highlight the incentive problem.

[25] This is assumed to simplify the problem. A similar assumption can be found in Hemmer (1995) and Cremer (1995).

Figure 3-2: Game Tree: Team Information System



Step 1: Agent 1 chooses his effort level (e_1 = h or l).

Step 2: x_1 is realized (x_g or x_b). $Prob(x_1 = x_g : e_1) = p_{e1}$, and $Prob(x_1 = x_b : e_1) = 1 - p_{e1}$.

Step 3: Agent 2 chooses his effort level (e_2 = H or L).

Step 4: x_2 is realized. $Prob(x_2 = x_G : x_1, e_2) = q_{e2,x1}$, and $Prob(x_2 = x_B : x_1, e_2) = 1 - q_{e2,x1}$.

agents are evaluated and compensated based on the outcomes of both the intermediate and final products.

3.3.1 Team information system

Suppose that the principal decides not to introduce the inspection system. Then, both agents are evaluated and compensated based on the team outcome, x_2. Since, by assumption, the principal desires to motivate the high effort level from both agents (i.e., $e_1^* = e_h$ and $e_2^* = e_H$), the optimal compensation schedules (s_1^* and s_2^*) must satisfy the following problem:

$$\min_{s_1, s_2} \quad E(s_1(e_h, e_H)) + E(s_2(e_h, e_H))$$

subject to

$$E(s_1(e_h, e_H)) - c_1(e_h) \geq 0$$

$$E(s_2(e_h, e_H)) - c_2(e_H) \geq 0$$

$$E(s_1(e_h, e_H)) - c_1(e_h) \geq E(s_1(e_l, e_H)) - c_1(e_l)$$

$$E(s_2(e_h, e_H)) - c_2(e_H) \geq E(s_2(e_h, e_L)) - c_2(e_L)$$

$$s_1(x_G) - c_1(e_h) \geq 0$$

$$s_1(x_B) - c_1(e_h) \geq 0$$

$$s_2(x_G) - c_2(e_H) \geq 0$$

$$s_2(x_B) - c_2(e_H) \geq 0$$

Let Δ_i be the difference between agent *i*'s disutility of high effort and his disutility of low effort: $\Delta_1 = c_1(e_h)-c_1(e_l)$ and $\Delta_2 = c_2(e_H)-c_2(e_L)$. For simplicity, asterisks are henceforth omitted. The compensation schedule under the team information system is summarized in the following lemma:

Lemma 3.1: *Assume that (i) the principal chooses to use a team information system, and (ii) decides to induce the high effort levels from both agents. Then, the optimal contract is:*

$s_1(x_B) = c_1(e_h);$

$s_1(x_G) = \Delta_1 / ((p_h-p_l)(q_{H,g} - q_{H,b})) + c_1(e_h);$

$s_2(x_B) = c_2(e_H);$

$s_2(x_G) = \Delta_2 / (p_h\, \theta_g + (1-p_h)\theta_b) + c_2(e_H).$

Proof: See appendix 1.

Lemma 3.1 permits an evaluation of the bonus, defined as follows:

Definition (Bonus): The bonus for quality is the difference between the expected compensation for the high-quality final outcome and the expected compensation for the low-quality final outcome.

Lemma 3.1 implies that the first agent's bonus resulting from good quality of the second product decreases as (i) the difference in disutilities of the two effort levels (Δ_1) decreases; (ii) (p_h-p_l), the increase in the probability of the good-quality first product due to the first agent's effort increases, is larger;[26] and (iii) the externality realized by high effort (v_H) is larger.[27] Based on (ii) and (iii), it can be concluded that the team information system leads to a smaller bonus when the first agent's effort choice has a large impact on the quality of the second product. The externality plays a critical role. The effectiveness of the team information system depends on the degree of the externality created by the first agent's effort. Intuitively, the value of this system is determined by its ability to (correctly) evaluate the first agent's effort level without inspecting the direct result of his work. Since high externality implies that the quality of the second product reflects most of the first agent's effort, the use of the team information system is efficient and effective in the presence of the high externality. For example, if the externality realized by e_H is close to infinity (i.e., $q_{H,g} - q_{H,b} \approx 1$), the quality of the second product depends solely on the first agent's effort level and, therefore, the principal can have the maximum possible information x_2 can deliver. The principal gives a lower bonus, as she can acquire more accurate information about the effort level and, hence, there is less moral hazard.

Similarly, the second agent's bonus resulting from the good quality of the second product decreases as (i) the difference in disutilities of two effort levels (Δ_2) decreases, (ii) $q_{H,g}$ or $q_{H,b}$ increases, and (iii) $q_{L,g}$ or $q_{L,b}$ decreases. The last two conclusions stem from the

---

[26] To induce e_h, $p_h s_1(x_G)$ must be sufficiently larger than $p_\ell s_1(x_G)$. In other words, $(p_h - p_\ell)s_1(x_G)$ must be large enough. If $(p_h - p_\ell)$ is small, then $s_1(x_G)$ must be large to motivate the high effort level.

[27] A large externality implies that $q_{H,g}$ is significantly higher than $q_{H,b}$. The first agent's high effort is required to produce the good-quality first product, which increases the chance of realization of the good-quality second product. Therefore, to induce the first agent's high effort, the smaller the impact of the first-product quality on the second-product quality, the larger $s_1(x_G)$ must be.

fact that the second agent's bonus decreases as the second agent's effort effectiveness (i.e., θ_g or θ_b) increases. Therefore, it can be concluded that the team information system leads to a smaller bonus when the second agent's effort choice has a large impact on the quality of the second product. Intuitively, if x_2 depends more on the second agent's effort, the principal can obtain more accurate information from x_2 about the second agent's effort level and, therefore, can decrease the bonus required to motivate the agent. Finally, if $\theta_g > \theta_b$, then the effect of the second agent's high effort on the final outcome given the good-quality intermediate product (i.e., $q_{H,g} - q_{L,g}$) is greater than the effect of the second agent's high effort on the final outcome given the bad-quality intermediate product (i.e., $q_{H,b} - q_{L,b}$). In this case, the quality of the final product can provide better information about the second agent's effort if the quality of the intermediate product is high. Since higher values of p_h represent a greater chance of the high-quality intermediate product, increases in p_h decrease the moral hazard problem associated with the second agent and, in turn, decrease the second agent's bonus. In contrast, if $\theta_g < \theta_b$, then the low-quality intermediate product delivers more information about the second agent's effort decision and, therefore, increases in p_h, which increase the moral hazard problem, result in a higher bonus.

3.3.2 Individual information system

Suppose that the principal decides to introduce the inspection system. Then, both agents are evaluated and compensated based on both the inspection outcome, I_1, and the quality of the second product, x_2. Assuming the principal's optimal solution is to induce high effort levels from both agents, the resulting compensation schedules are summarized in the following lemma:

Lemma 3.2: *Assume that (i) the principal chooses to use the individual information system, and (ii) decides to induce the high effort levels from both agents. Then, the optimal solution can be summarized as follows:*

$$s_1(I_g, x_B) = s_1(I_b, x_G) = s_1(I_b, x_B) = c_1(e_h);$$

$$s_1(I_g, x_G) = \Delta_1 / ((p_h - p_l)(q_{H,g} - (1-\beta)q_{H,b})) + c_1(e_h);$$

$$s_2(I_g, x_B) = s_2(I_b, x_B) = c_2(e_H);$$

$$s_2(I_g, x_G) = \Delta_2 / (\alpha_h\, \theta_g + (1-\alpha_h)\, \theta_b) + c_2(e_H);$$

$$s_2(I_b, x_G) = \Delta_2 / \theta_b + c_2(e_H),$$

where $\alpha_h = prob(x_g : I_g, e_h) = p_h / [p_h + (1-\beta)(1-p_h)]$.

Proof: See appendix 1.

Lemma 3.2 shows that the first agent receives no bonus if the inspection system reports a low-quality intermediate product. If the inspection system reports a high-quality intermediate product, the first agent can receive a bonus for the good quality of the final outcome and the bonus decreases as (i) the difference in disutilities of the two effort levels (Δ_1) decreases; (ii) (p_h-p_l), the increase in the probability of the good-quality first product resulting from the first agent's effort increase, is larger;[28] (iii) the externality realized by the

[28] This implies that the individual incentive system leads to a smaller wage premium when the first agent's effort choice has a big impact on the *inspection result.*

second agent's high effort, v_H, increases; and (iv) the accuracy of the inspection system (β) is higher. The accuracy of the inspection system plays an important role in this case. For example, if the inspection system were perfect (i.e., β=1), the bonus would be the smallest and would compensate only for disutility induced by high effort, adjusted by a random state of nature in the second production process. As the accuracy decreases, the bonus is increased to mitigate the moral hazard problem introduced by inaccuracy.[29] Therefore, the accuracy of the system is a critical factor in determining the efficacy and efficiency of the system.

Given the good inspection result, the second agent's bonus for the good quality of the second product decreases as (i) the difference in disutilities of two effort levels (Δ_2) decreases, (ii) $q_{H,g}$ or $q_{H,b}$ increases, and (iii) $q_{L,g}$ or $q_{L,b}$ decreases. The last two results imply that the principal provides a smaller bonus when the second agent's effort choice has a large impact on the quality of the second product. In this case, the principal can decrease the bonus required to motivate the agent since the principal can glean more accurate information from x_2 about the second agent's effort level. Finally, the second agent's bonus decreases as α_h increases if $\theta_g > \theta_b$. In this case, the quality of the final product can provide better information about the second agent's effort if the quality of the intermediate product is high. Since higher values of α_h represent a greater chance of the high-quality intermediate product given the high inspection report, increases in α_h decrease the moral hazard problem associated with the second agent, and in turn, decrease the second agent's

[29] Since the inaccurate inspection system is not able to determine the first agent's effort choice, the inaccuracy permits opportunistic behavior.

bonus. Conversely, if $\theta_g < \theta_b$, then the case of the low-quality intermediate product delivers more information about the second agent's effort decision and, therefore, increases in α_h, which increase the moral hazard problem, result in a higher bonus. Given the bad inspection result, the second agent's bonus for good quality of the second product decreases as (i) the difference in disutilities of the two effort levels decreases and (ii) the second agent's effort effectiveness given the bad-quality intermediate product ($\theta_b = q_{H,b} - q_{L,b}$) increases. In general, the bonus for x_G decreases as the impact of the second agent's effort choice on quality increases.

3.4 Optimal Information System

In this section, the bonuses and the principal's expected utility based on the results derived in the previous sections are compared. The bonuses are examined for two reasons. First, the bonus reflects a specific contract item that is used in the real world. Since the expected wages, the agent's expected utilities, and the principal's expected utilities are not directly observable, the comparison of bonuses can reveal predictions that have testable implications. Second , and more importantly, the comparison of the bonuses provides useful insights into the incentive problems associated with each information system. Intuitive explanations and predictions of the principal's expected utilities can be obtained by examining bonuses.

3.4.1 Quality Bonus

The bonus for agent 1 under the team information system (B_1^T) is $\Delta_1/((p_h-p_\ell)(q_{H,g}-q_{H,b}))$, whereas the bonus for agent 1 under the individual information system (B_1^I) is $\Delta_1/((p_h-p_\ell)(q_{H,g}-(1-\beta)q_{H,b}))$. It is evident that $B_1^T - B_1^I \geq 0$ since $1 \geq \beta \geq 0$. The principal pays more bonus to agent 1 if the team information system is used, and the difference increases as the accuracy of the individual performance measure increases. It is clear that the individual performance measure decreases the moral hazard problem associated with the first agent and, therefore, decreases the principal's expected costs in inducing the first agent's effort.

Although individual information about the quality of the intermediate product has a clear advantage in inducing the first agent's effort, it is not clear if it has an advantage in inducing the second agent's effort. To see this, consider the bonuses for agent 2 under each information system. The bonus for agent 2 under the team information system (B_2^T) is $\Delta_2 / (p_h\, \theta_g + (1-p_h)\, \theta_b)$. The bonuses for agent 2 under the individual information system are $B_2^g = \Delta_2 / (\alpha_h\, \theta_g + (1-\alpha_h)\, \theta_b)$ if I_g is realized and $B_2^b = \Delta_2 / \theta_b$ if I_b is realized.

Observation 3.1:

(1) Suppose $\beta \in [0, 1)$. If $\theta_g > \theta_b$, then $B_2^g < B_2^T < B_2^b$. If $\theta_g < \theta_b$, then $B_2^g > B_2^T > B_2^b$. If $\theta_g = \theta_b$, then $B_2^g = B_2^T = B_2^b$.

(2) Suppose $\beta = 1$. If $\theta_g > \theta_b$, then $B_2^g = B_2^T < B_2^b$. If $\theta_g < \theta_b$, then $B_2^g = B_2^T > B_2^b$. If $\theta_g = \theta_b$, then $B_2^g = B_2^T = B_2^b$.

Proof: See appendix 1.

Suppose the second agent's effort effectiveness is higher with the good-quality intermediate product than with the bad-quality intermediate product: $\theta_g > \theta_b$. Then, the principal should pay more (less) bonus under the individual information system than under the team information system if the inspection system reports the bad-quality (good-quality) intermediate product. The reason for this stems from the fact that the outcome of the final product is a relatively better information source given the good-quality intermediate product than given the bad-quality intermediate product if $\theta_g > \theta_b$. Therefore, the moral hazard problem is less severe given the good-quality intermediate product than given the bad-quality intermediate product if $\theta_g > \theta_b$. Since the inspection system informs the principal and the second agent about the quality of the first product, the second agent uses this information for his decision. If the inspection system informs the second agent that the quality of the first product is bad, then the true quality of the first product is bad. In this case, the principal should pay a higher bonus because she must compensate the second agent's lower effort effectiveness with a higher bonus to induce the second agent's high effort. Conversely, if the inspection system informs the second agent that the quality of the first product is good, the premium based on the inspection result (I_g) can be smaller than the bonus based on the prior probability (p_h) because I_g guarantees a high proportion of x_g and x_g increases the effort effectiveness.

Another important observation is that the accuracy of the inspection system is not a factor in determining the relative size of the bonuses. The relative level of the bonuses are determined by the second agent's effort effectiveness regardless of the accuracy of the individual inspection system. Although an accurate inspection system about the first agent's performance clearly helps to relieve the moral hazard problem with respect to the first agent, it has mixed effects on the moral hazard problem with respect to the second agent. Depending on the second agent's effort effectiveness, an accurate inspection system often aggravates the second agent's moral hazard problem. This can be explained more clearly by examining the principal's expected costs.

3.4.2 Principal's expected costs

Since the expected revenues from the second product are the same regardless which compensation scheme is used, comparisons of the principal's expected return focus on the expected wages for both agents. Agent 1's expected wage, which is the principal's expected cost with respect to agent 1, under the team information system (W_1^T) is

$$c_1(e_h) + ((p_h\, q_{H,g} + (1-p_h)q_{H,b})\Delta_1) \,/\, ((p_h - p_l)(q_{H,g} - q_{H,b})), \qquad (3.1)$$

whereas agent 1's expected wage under the individual information system (W_1^I) is

$$c_1(e_h) + ((p_h\, q_{H,g} + (1-\beta)(1-p_h)q_{H,b}))\Delta_1 \,/\, ((p_h - p_l)(q_{H,g} - (1-\beta)q_{H,b})). \qquad (3.2)$$

A straightforward calculation shows $W_1^T - W_1^I \geq 0$ since,

$$\begin{aligned} &(p_h\, q_{H,g} + (1-\beta)(1-p_h)q_{H,b}) \,/\, (p_h - p_l)(q_{H,g} - (1-\beta)q_{H,b}) \\ &\quad \leq (p_h\, q_{H,g} + (1-p_h)q_{H,b}) \,/\, (p_h - p_l)(q_{H,g} - (1-\beta)q_{H,b}) \\ &\quad \leq (p_h\, q_{H,g} + (1-p_h)q_{H,b}) \,/\, ((p_h - p_l)(q_{H,g} - q_{H,b}). \end{aligned} \qquad (3.3)$$

Therefore, the principal's expected cost with respect to agent 1 under the individual information system is less than those under the team information system. Furthermore, the difference in the expected cost increases as the accuracy of the information system (β)

increases. This result is intuitive because the individual information system can reveal more information about the first agent's effort than the team information system does.

The second agent's expected wage under the team information system (W_2^T) is

$$c_2(e_H) + ((p_h\, q_{H,g} + (1-p_h)q_{H,b})\Delta_2) /(p_h\, \theta_g + (1-p_h)\, \theta_b), \tag{3.4}$$

whereas agent 2's expected wage under the individual information system (W_2^I) is

$$c_2(e_H) + ((p_h\, q_{H,g} + (1-\beta)(1-p_h)q_{H,b}))\Delta_2 /(\alpha_h\, \theta_g + (1-\alpha_h)\, \theta_b) + (\beta(1-p_h)\, q_{H,b})\Delta_2 / \theta_b. \tag{3.5}$$

The difference is:

$$W_2^T - W_2^I = \frac{-\beta\, (p_h^2)\, (1-p_h)\, (q_{L,g}q_{L,b})\, (\theta_g - \theta_b)\, (v_H - v_L)\Delta_2}{\theta_b\, (p_h\, \theta_g + (1-p_h)\, \theta_b)\, (p_h\, \theta_g + (1-\beta)(1-p_h)\, \theta_b)} \tag{3.6}$$

Proposition 3.1 summarizes this comparison:

Proposition 3.1: *The expected wage for agent 1 is lower under the individual information system than under the team information system. The expected wage for agent 2, however, is lower under the team information system than under the individual information system if (i) $v_H > v_L$ or (ii) $\theta_g < \theta_b$.*

Proof: See appendix 1.

As discussed in the previous section, proposition 3.1 shows that the individual information system is always beneficial for the principal in inducing the *first* agent's effort. Since the individual information system has more information about the first agent, the principal can be better off with respect to the first agent by using this system as compared to the team information system. The individual information system may not beneficial, however, and may be harmful, for the principal in inducing the *second* agent's effort. Proposition 3.1 suggests that using the individual inspection system can be an expensive way to motivate the second agent. This is because the second agent observes the inspection report and uses the information for determining his effort. Given the agents' limited liability, the principal cannot sufficiently penalize the second agent for a bad-quality second product. Since she cannot use "the stick," her incentive system must be based on "the carrot." To motivate the high effort level, each information system provides a relatively bigger reward for a good-quality second product under an unfavorable situation. In this case, the inspection report can be costly for the principal in terms of motivating the second agent.

First, if the externality realized by the second agent's high effort is bigger than the externality realized by the second agent's low effort, then it is very difficult to induce the second agent's high effort given the bad-quality inspection report. The large externality realized by the second agent's high effort implies that it is important to have the good-quality intermediate product to produce the good-quality final product with the second agent's high effort.[30] If the inspection system reports the bad-quality intermediate product, then the second agent's high effort is not effective in increasing the quality of the final product, and therefore, the quality of the final product is not informative of the second agent's effort. In this case, the principal pays higher wages to counteract the agent's shirking incentive. Since the team information system avoids this problem by not

---

[30] The reason is that $v_H > v_L$ implies that $(q_{H,g} / q_{L,g}) > (q_{H,b} / q_{L,b})$.

generating an inspection report, it is more beneficial, at least in terms of the second agent's incentive problem, to use the team information system than to use the individual information system.

The second case in proposition 3.1 is the opposite of the first case, but the intuition is similar. Both the lower externality realized by the high effort and the lower high-effort effectiveness make it difficult to motivate the second agent to work hard if a good-quality intermediate product is reported. In this case, the principal provides higher incentives if the good-quality intermediate product is reported. This higher incentive requirement outweighs the benefit of a lower incentive requirement in case of a bad-quality intermediate product.

The individual information system is efficient in inducing the second agent's high effort if and only if $v_H < v_L$ and $\theta_g > \theta_b$. In this case, the incentive problem associated with the higher externality realized by the low effort is mitigated by the higher effort effective on the good-quality intermediate product. These two effects remedy the incentive problems associated with each effect, and make it possible to realize the benefit associated with the individual information system.

Interestingly, the accuracy of the individual inspection system is not a determinant of the efficiency of the individual information system. Moreover, the more accurate inspection system actually hurts the principal with respect to the second agent if (i) $v_H > v_L$ or (ii) $\theta_g < \theta_b$:

Corollary 3.1: *Suppose either (i) $v_H > v_L$ or (ii) $\theta_g < \theta_b$. Then, an increase in the accuracy of the individual inspection system increases the principal's expected costs with respect to the second agent.*

Proof: The corollary follows from equation (3.6) and proposition 3.1. □

This result is intuitive. If the team information system is better than the individual information system in inducing the second agent's effort, then the individual performance measure actually aggravates the second agent's incentive problem. In this case, more accurate information simply worsens the incentive problem by providing more opportunity for the second agent's adaptive behavior (i.e., shirking). Whereas the principal always realizes the benefit of an accurate inspection system with respect to the first agent, the associated costs with respect to the second agent may exceed the benefit. The following numerical example illustrates how a more accurate inspection system increases the principal's expected costs relative to the team information system.

Example 3.1: Suppose the following parameter values: Δ_1 = \$1000; Δ_2 = \$7000; $p_h = 0.7$; $p_l = 0.2$; $q_{H,g} = 0.8$; $q_{H,b} = 0.5$; $q_{L,g} = 0.4$; $q_{L,b} = 0.4$.[31] Then,

$$W_1^T + W_2^T - (W_1^I + W_2^I) = \frac{\$45165\,\beta\,(\beta - 0.691)}{(\beta - 10.333)(\beta + 0.6)}.$$

Since $1 \geq \beta \geq 0$, $(W_1^T + W_2^T) < (W_1^I + W_2^I)$ if $\beta > 0.691$. Therefore, in this case, the more accurate information system actually hurts the principal because of the much higher

---

[31] This example illustrates the case of $v_H > v_L$.

magnitude of the incentive wages with respect to the second agent. (1) Suppose that β = 0.5. In this case, $W_1^T - W_1^I$ = \$2424.37 and $W_2^T - W_2^I$ = -\$2025.37. Clearly, this system is beneficial with respect to the first agent's incentive problems, but not beneficial with respect to the second agent's incentive problems. The benefits of the individual information system dominate its costs, however, and, therefore, the inspection system is overall beneficial. (2) Now, suppose $\beta = 1$. This system is perfect for both good-quality and bad-quality products. Then, $W_1^T - W_1^I$ = \$3333.33 and $W_2^T - W_2^I$ = -\$4267.74. Although this perfect system increases the benefits of the individual information system with respect to the first agent by about \$909, it also increases the principal's expected costs with respect to the second agent by approximately \$2242. As a result, the principal's total expected costs increases from \$398.87 to \$1333. This change is enough for the principal to give up the individual information system and use the team information system. Therefore, an accurate information system is not always better than an inaccurate information system even ignoring the cost of the underlying information system. In this case, the externality, the effort effectiveness, and the limited liability jointly determine the desirability of better (costless) individual information system. (3) Finally, suppose $\beta = 0$. Then the information system does not provide any information about the quality of the intermediate product. In this case, there are no benefits or costs associated with the agents' motivation. Hence, the two information systems are identical. (4) The individual information system is optimal if and only if $0 < \beta < 0.691$, and the team information system is optimal if and only if $\beta > 0.691$. The principal is indifferent about the two information systems if $\beta = 0$ or if β =0.691.

The above example demonstrates that there is an optimal range of information accuracy which makes the individual information system beneficial to the principal even if it enables the second agent's adaptive behavior. If the accuracy is too high, the individual information system is not optimal because the costs associated with the second agent's motivation are too large.

3.4.3 Optimal individual information system

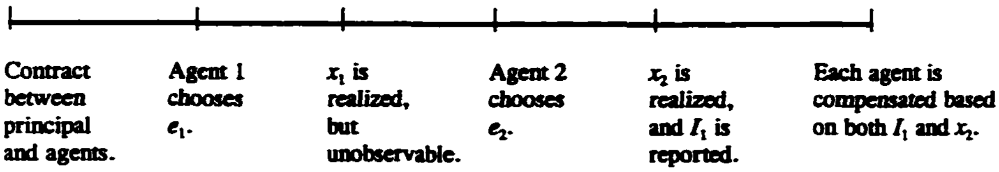
3.4.3.1 Delayed individual information system

In the previous section, I show that the individual information system can make the principal worse off because of the second agent's possible adaptive behavior. This problem is easily rectified if the principal can commit herself not to reveal the inspection report until the second agent completes his task. It is, however, impossible to keep this commitment once the inspection report is available.[32] For example, suppose $v_H > v_L$. Then, the principal can be better off by not revealing the bad-quality report to the second agent since the bad-quality report makes it difficult to motivate the second agent's effort. Once the principal receives the good-quality report, however, she has a clear incentive to reveal the good-quality report because the revelation would allow her to decrease the expected compensation costs. Since the principal reveals the good-quality report but keeps the bad-quality report, the second agent can infer the inspection results from the principal's behavior. In this case, the problem associated with the second agent's adaptive behavior

---

[32] Furthermore, it is unrealistic to assume that only the principal can observe the inspection results.

Figure 3-3: Sequence of Events (Delated Individual Information System)



cannot be rectified. Hence, the principal should not have any information about the quality of the intermediate product if she wants to avoid the second agent's adaptive behavior.

There is a feasible way to commit herself not to exploit the inspection results until the second agent completes his task. Suppose that the inspection system reports the quality of the intermediate product after the final product is produced. The timing of contracts based on this information system is summarized in Figure 3-3. In this case, neither the principal nor the agents have any private information about the quality of the intermediate product. Therefore, the principal easily commits herself not to exploit the inspection results. Furthermore, since the information about the quality of the intermediate product is available as public information after the second agent finishes his task, the principal can use this information as a performance measure; therefore, she can realize the benefit of additional information without the non-desirable second agent's adaptive behavior.

Proposition 3.2: *The delayed individual information system (weakly) dominates the team performance system.*

Proof: See appendix 1.

One interesting example of this type of information system occurred at Buick, which asked workers to engrave their names on a specific unit of the Reata model and gave incentives based on future problems of the unit (Hemmer, 1995). Moreover, if the market of the final product is sophisticated with respect to the quality of the product, this type of information can be obtained from the market without introducing a formal information system within the firm.

3.4.3.2 Optimal accuracy of the inspection system

In the previous sections, I assume that the accuracy of the individual inspection system is an exogenous variable. It is, however, possible that the principal designs the inspection system by choosing its accuracy. The increase in accuracy leads to two countervailing effects. While it always reduces the moral hazard problem with respect to the first agent, it increases the costs associated with the second agent's adaptive behavior. Therefore, the principal may choose not to increase the accuracy beyond a certain level even though there are no direct costs associated with the increase in accuracy. The following example shows that there exists an optimal level of accuracy to balance these two countervailing effects.

Example 3.2: (1) Consider the case in example 3.1, where $v_H = 1.5 > v_L = 1$. If the principal can choose the level of the accuracy (β) in that case, her problem under the individual information system is to minimize the expected costs (EC_p) with respect to β:

$$\text{Min}_\beta\ EC_p = \frac{24400\,(\beta + 0.859)\,(\beta + 6.126)}{(10.333 - \beta)\,(\beta + 0.6)}.$$

A straightforward first-order condition approach reveals

$$\partial EC_p / \partial\beta = \frac{408400\,(\beta - 0.286)\,(\beta + 0.6)\,(\beta + 1.657)}{(10.333 - \beta)^2\,(\beta + 0.6)^3},$$

and

$$\partial^2 EC_p / \partial\beta^2 = \frac{816800\,(\beta + 3.301)\,(\beta + 0.6)\,(2.685 - 1.244\,\beta + \beta^2)}{(10.333 - \beta)^3\,(\beta + 0.6)^3}.$$

Since $\partial^2 EC_p / \partial\beta^2 > 0$ for $\beta \in [0, 1]$, the optimal level of the accuracy, β^*, is 0.2859. Therefore, the optimal information system under the given parameter values is the individual information system with accuracy of 0.2859. This case shows that the principal is worse off if she chooses the individual inspection system with accuracy greater than (or less than) 0.2859. (2) Now suppose that v_H is increased from 1.5 to 1.8862 by increasing $q_{H,g}$ from 0.8 to 0.9431. In this case, the optimal accuracy of the individual inspection system β^* is 0. Therefore, the principal never uses the individual inspection system, and adopts the team information system. Furthermore, this example shows that the team information system is optimal if the externality realized by the second agent's high effort is sufficient.

3.5 Conclusion

This chapter investigates which performance measures should be used in evaluating employees to make cooperative and product-oriented teams work when externalities exist between team members' performance and the outcomes of some tasks are unobservable. Examination of these areas is important because modern manufacturing techniques often necessitate dramatic changes in organizational forms (including teams) and performance measurement systems. Using the model reflecting a sequential manufacturing process, my research addresses these issues and shows that an imperfect individual-performance inspection system leads to inefficient results, given sufficient externality in the production processes and agents' limited liability. Specifically, by introducing the second employee's adaptive behavior following an inspection report, the model shows that a team information system is better than an individual information system when: (1) the realization of the externality increases as the agent's effort increases or (2) the realization of the externality decreases as the agent's effort increases and the effects of the agent on his performance decreases as the other agent's performance increases. In both cases, the agent utilizes information about the other agent's performance to decide his effort level. This decision-facilitating effect of the individual information increases the principal's expected costs of inducing the agent's desirable effort. Furthermore, as the accuracy of the individual information system increases, this negative effect of the individual information system increases. Finally, if the principal can commit herself not to reveal individual information before the second agent makes his effort decision, individual performance measures are valuable. As such commitment is not possible under most information systems, the principal may decide to delay the inspection until all production processes are finished.

There are several future research areas to examine. First, the current model does not include various modern manufacturing and management concepts. For example, Just-

In-Time and Flexible Manufacturing Systems (FMS) change the manufacturing processes and the relationships among agents. As a result, understanding interactions between those changes and organizational structures becomes important in business success. Moreover, these interactions can be viewed as a part of complementarity relationships existing in modern business (Milgrom and Roberts, 1990, 1994, 1995). Complementarity relationships between those changes in manufacturing and management concepts and team-oriented organizational structures motivate an extensive emphasis on teams. Therefore, future research should include a rich set of manufacturing and management practices and examine the efficiency and effectiveness of team-oriented approaches. Second, the relationships between performance measures and multiple tasks for each team member can be examined, specifically in the case in which the outcomes of some tasks are not contractible. The analysis of this case will provide insight about efficient performance measures when some team members' performance is not verifiable. Third, this research can be extended to the case of temporary problem-solving teams which may not have observable short-time performance measures, and whose team members may feel conflict between their usual roles as functional experts and their temporary problem-solver roles.

Chapter 4. Cooperation Decisions and Incentives

4.1 Introduction

As discussed more fully in chapter 2, the use of teams in organizations has increased dramatically in the past decade (Dumain, 1994). The key to team success in the current competitive environment is "synergy effects," or "cooperative performance increases."[33] It is argued, however, that cooperative performance increases in teams can be facilitated by well-designed performance measurement and incentive systems. For example, facing a piece-rate compensation system, teams may pressure a team member into lower productivity so as not to make other team members' productivity low (Larson and LaFasto, 1989). Teams may be successful in realizing performance increases when firms develop appropriate performance measurement and incentive systems which encourage the desired teamwork to overcome the problems in traditional management accounting systems.

This chapter uses a principal-multiagent framework to examine optimal incentive systems in the face of cooperation and synergy opportunities. Since team success often depends on the realization of cooperation and synergy opportunities, it is important to align incentive systems with cooperation opportunities to maximize the benefits of cooperation. For example, consider a product designer and a salesperson whose performance measures

---

[33] Katzenbach and Smith (1993) summarize the sources of synergy effects as (i) complementary skills and experiences, (ii) communications, (iii) a unique social dimension such as trust and confidence, and (iv) more fun.

are the customer acceptance of the product design and sales revenues, respectably. Suppose both employees are cooperative in the following sense: the salesperson provides information about target customers' characteristics to the designer and the product designer is willing to incorporate such information into the product design. The salesperson's information and the product designer's willingness enable the designer to develop a product design which appeals to the target customers. Furthermore, better customer acceptance of the product design can increase sales revenues if the salesperson exercises proper sales efforts. In this case, cooperation results in better customer acceptance of the product design and increases in sales revenues. These benefits of cooperative activities, however, cannot be realized either if the salesperson decides not to provide information or if the designer decides not to incorporate the salesperson's information into the product design. This example illustrates a situation in which it is critical to have both agents' cooperation to be a successful team. The success of the designer-salesperson team depends on both the designer's willingness to utilize the salesperson's information and the salesperson's willingness to provide valuable information. If one party does not wish to cooperate, the synergy effects cannot be realized.

The above relationship captures the concept of cooperation and synergy which can be achieved through teams. Indeed, Abramis (1990) argues that the goal of a team is the production of high quality products as a result of team members' combined efforts, not one or two members' excellent performance. In this chapter I examine the characteristics of various compensation contracts and conditions under which the benefits of cooperation can be efficiently realized. To model cooperation, I assume each agent makes a cooperation decision before making any work decision. Cooperation is assumed to require no additional effort, and the agent's decision can be either cooperation or noncooperation. If both agents decide to be cooperative, then the probability of each agent's task success under an unfavorable environment increases. On the other hand, if one of the agents decides to be noncooperative, then both agents cannot have any increase in the probabilities. These probability increases can be considered synergies from the agents' cooperative behaviors. Finally, under a favorable environment, both agents' tasks are successful regardless of cooperation or work decision.[34]

The analysis of this cooperation decision results in several interesting implications for performance evaluation and incentive contracts. First, the model is analyzed to investigate optimal performance evaluation systems given that the benefits of cooperation are realized only if both agents cooperate and work hard (i.e., "*inseparable*" cooperation and work decisions). The results demonstrate that an agent may not cooperate under competitive performance evaluation (e.g., tournament-based relative performance evaluation) even though cooperation benefits his own performance. This is because, under competitive performance evaluation, cooperation may decrease the agent's expected rewards since it increases the other agent's performance as well as his own. Since the agent has an incentive to decrease, or at least not increase, the other agent's performance under competitive performance evaluation, the agent may give up possible increases in his own performance and decide not to cooperate to prevent increases in the other agent's

---

[34] In this chapter, therefore, the common environmental shock to both agents' performance may be favorable or unfavorable.

performance if cooperation significantly increases the other agent's performance. This is true even if there is no additional efforts associated with cooperation and the effects of cooperation on each agent's performance are the same. Therefore, if the effects of cooperation are significant, team-oriented performance evaluation is used in the following way: the principal has an agent responsible for the success of both his and the other agent's tasks (i.e., joint performance evaluation). The benefits of team-oriented performance evaluation stem from its ability to direct agents to the success of others and to provide a clear incentive for cooperation. As the benefits of cooperation increase, team-oriented performance evaluation becomes more efficient in inducing cooperation than competitive performance evaluation.

Second, the results show that team-oriented performance evaluation becomes an efficient scheme in inducing cooperation as (1) the effects of shirking behaviors on performance are closer to those of hard-working, (2) the effects of hard-working on performance increase with significantly large synergies, or (3) the effects of hard-working decrease with sufficiently small synergies. If the effects of cooperation are small, team-oriented performance evaluation becomes more efficient as the "productivity" increases due to hard work, which can be defined as the difference between the effects of hard-working and those of shirking behaviors on performance, decreases. If, however, the effects of cooperation are significant, increases in the effects of either shirking or hard-working make team-oriented performance evaluation more efficient.

Finally, I examine the implications of the inseparable-cooperation assumption on optimal performance evaluation systems. The model continues to assume that the benefits of cooperation are realized only when both agents cooperate, but no longer assumes that cooperative behaviors require hard-working. Hence, it is possible for an agent to enjoy the benefits of cooperation if both agents cooperate and one agent works hard regardless of the other agent's work decision. In this "*separable*" decision case, the analysis shows that team-oriented performance evaluation provides the agents not only an incentive for cooperation but also an incentive for shirking. Under team-oriented performance evaluation, an agent can increase his chance of receiving wages simply by cooperating and, therefore, increasing the other agent's probability of success. Consequently, team-oriented performance evaluation provides an incentive for shirking while providing an incentive for cooperation. This negative effect of team-oriented performance evaluation increases as a cooperation decision and a work decision become more separable. Another option for preventing this type of free-riding behavior is competitive performance evaluation. Competitive performance evaluation, however, may not provide enough incentive for cooperation since cooperation benefits the other agent. To balance these two conflicting incentives, the principal utilizes "independent performance evaluation." By employing independent performance evaluation, the principal can provide incentives for both working and cooperation. Furthermore, the results show that there exists an inverse (positive) relationship between the benefits of team-oriented (independent) performance evaluation and the separability of a cooperation decision and a work decision.

Through introducing the concept of cooperation into the model, the chapter shows the benefits of team-oriented performance evaluation even if there exist common environmental shocks. As Holmstrom (1982) shows, competition-oriented relative performance evaluation is valuable if the agents face common uncertainty under which an agent's output provides information about another agent's state of nature.[35] The clear advantages of competitive performance evaluation schemes are decreasing agents' risk from common environmental shocks and decreasing information asymmetry problems. If the effects of cooperation on task success are significant, however, competitive performance evaluation is not an effective scheme to motivate cooperation.

Itoh (1991, 1992) and Hemmer (1995) model the possibility of technological synergies among team members and examine their effects on incentive contracts.[36] Itoh (1991, 1992) posits that positive helping effort (defined as teamwork) is optimal to the principal and that joint performance evaluation should be used when there is a complementarity relation between helping effort and own effort. Itoh (1992) shows that full side-contracting is better if the agents are sufficiently similar in terms of utility and cost functions and can monitor each other's efforts. Hemmer (1995), modeling a sequential production process, shows that the principal can induce higher quality-enhancing efforts by assigning all tasks to an agent (i.e., craftsmanship) if the quality of the product is not observable. Hemmer's results stem from the assumptions that (i) individual performance measures are not able to evaluate the effects of the quality-enhancing efforts and (ii) an agent's quality enhancing efforts have no effect on his own performance but

---

[35] As discussed more fully in chapter 2, other researchers, such as Lazear and Rosen (1980), Green and Stokey (1983), Nalebuff and Stiglitz (1983), and Mookherjee (1984), have studied relative performance measurement in the context of the interrelationship based on common environmental factors.

[36] Chapter 2 provides the details of these papers.

decrease the other agent's disutility associated with productive activity. Therefore, the principal can induce positive helping (i.e., quality-enhancing) efforts by assigning all tasks to each agent and evaluating him based on the outcomes of both tasks.

While Itoh (1991, 1992) and Hemmer (1995) examine the case in which each agent can provide a helping effort to the other agent, not necessarily increasing his own performance, I model a synergy effect of cooperation on both agents' performance and the effects of the relationship between the cooperation decision and the work decision on the incentive contract. The results show that it may be expensive to induce an agent to cooperate under competitive performance evaluation even though cooperation benefits his own performance as well as the other agent's. Furthermore, it is shown that the relationship between the realization of the benefits of cooperation and the work decision (i.e., separability) is an important determinant of the optimal incentive contract. Finally, in contrast to Hemmer (1995), the model in this chapter specifies the situation where individual performance measures can indirectly evaluate the effects of the cooperation decision and individual specialties preclude changes in task allocations. Consequently, the model in this chapter relaxes Hemmer's assumption about the characteristic of performance measures and provides insights about team-oriented performance evaluation of specialists facing cooperation opportunities.

The following section explains the principal-multiagent model and specifies the optimal compensation contract if the cooperation decision and work decision are not separable. Section 4.3 examines the case where the cooperation decision and work decision can be made separate. Conclusions are provided in Section 4.4.

Figure 4-1: Sequence of Events

Contracts between principal and agents	Both agents' decisions on cooperation ($d_i \in \{0, 1\}$)	Both agents' decisions on work ($e_i \in \{0, 1\}$)	Outcomes are realized. ($x_i \in \{0, 1\}$)	Both agents are compensated.
^	^	^	^	^
t_1	t_2	t_3	t_4	t_5

4.2 Inseparable Cooperation Decision

In this section, the inseparable-cooperation model is explained and the optimal performance evaluation system is specified.

4.2.1 Model

The model includes a principal who hires two agents to work on two tasks.[37] Agent i takes charge of task i, $i = 1, 2$. The information system is assumed to generate performance measures x_i, i=1, 2. The performance measure x_i is a function of the work effort e_i and cooperation decision d_i of agent i, a common environmental factor, and an idiosyncratic random state of nature. The outcome of each task is assumed to be as either a success (one) or a failure (zero): $x_i \in \{0, 1\}$. The sequence of the events is illustrated in Figure 4-1.

---

[37] The model is consistent with Che and Yoo (1997)'s model. While Che and Yoo (1997) examine the effects of continuous relationships between agents on incentive contracts without considering a cooperation opportunity in multiple periods, this chapter focuses on the effects of the cooperation decision on incentive contracts.

The work effort put in by agent *i*, e_i is either zero ("shirk") or one ("work"), and the cost of one unit of effort is assumed to be *e*.[38] The common environmental shock is either favorable or unfavorable for both projects. The probability of a favorable environmental shock is σ, $1 > \sigma > 0$. For simplicity, it is assumed that the favorable environmental shock guarantees that both projects are successful regardless of the agents' efforts. If the environmental shock turns out to be unfavorable, the probability of task *i*'s success is p_{ei} if agent *i*'s effort is $e_i \in \{0, 1\}$: $1 > p_1 > p_0 \geq 0$.

Before making any work decision, each agent makes a cooperation decision which requires no additional effort. The cooperation decision made by agent *i*, d_i is either zero ("noncooperative") or one ("cooperative"): $d_i \in \{0, 1\}$, $i = 1, 2$. If both agents decide to be cooperative, then the probability of task *i*'s success under the unfavorable environment increases by ε: $1\text{-}p_1 > \varepsilon > 0$.[39] If one of the agents decides not to be cooperative, then neither agent's probabilities increase. These probability increases can be considered synergies from the agents' cooperative behaviors.

The relationship between cooperation and work decisions is defined as "*inseparable*" if the benefits of the employees' simultaneous cooperation decisions are not

---

[38] "Shirk" means low (less than full) effort, which is normalized to zero for simplicity.

[39] Since the focus of the chapter is cooperation, negative cooperation or "sabotage" possibilities (i.e., $\varepsilon < 0$) are not considered. Sabotage cases are examined by Lazear (1989). He considers tournament schemes and models in which each agent determines two actions: his own production action and the (costly) action that *adversely* affects output of another, called "sabotage." He shows that RPE schemes lead to sabotage because agents benefit by their rivals' failure as well as by their own successes. Therefore, he argues that pay compression (i.e., pay equality) may be desirable to reduce sabotage.

realized without work efforts. For example, consider the previous example of the designer-salesperson team. In that team, cooperation implies the product designer's willingness to utilize the salesperson's information and the salesperson's willingness to provide information about the target customers. The product designer's willingness to utilize the salesperson's information, however, has no effect on the product design and sales revenues if he decides not to work at all (i.e., neglects to improve the product design). In this case, the product designer's "work" is a prerequisite for the realization of the positive benefits of "cooperation."

In contrast, the relationships are defined as "*separable*" if the benefits of the employees' simultaneous cooperation decisions can be realized without work efforts. Suppose, for example, the salesperson, who has to communicate information about the target customers to the product designer, decides to provide information to the designer while simultaneously deciding to shirk. Since the salesperson will not work hard, he may not enjoy possible sales increases due to design improvements. The benefits of information, however, can be enjoyed by the designer if the designer is willing to utilize information and to improve the product design even though the salesperson does not work. If the designer decides not to utilize information (i.e., "noncooperation"), then he cannot realize the benefits. Similarly, if the designer decides not to work (i.e., "shirk"), he cannot realize the benefits, either.[40] Therefore, it is possible for an agent to enjoy the benefits of

---

[40] Another example is a Ph. D student participating in a teaching improvement seminar. By sharing his past teaching experiences and looking for better teaching methods with other instructors, the Ph. D student can benefit others if they are willing to adopt the improved teaching methods. This cooperation, however, does not require the student to (continued...)

cooperation if both agents decide to cooperate regardless of the other agent's work decision.

In this section, the implications of the inseparable-cooperation decisions on performance evaluation systems are examined.[41] If the cooperative behaviors cannot have the effects without working, the probabilities of task i's success are defined as follows:[42]

$\Pr(x_i=1 \mid e_1=e_2=1, d_1=d_2=1) = \sigma + (1-\sigma)(p_1+\varepsilon);$

$\Pr(x_i=1 \mid e_i=1, e_j=0, d_1=d_2=1) = \sigma + (1-\sigma)p_1$, where $i \neq j$;

$\Pr(x_i=1 \mid e_i=1, d_1 \neq d_2) = \Pr(x_i=1 \mid e_i=1, d_1=d_2=0) = \sigma + (1-\sigma)p_1$, $\forall\, e_j$, $i \neq j$;

$\Pr(x_i=1 \mid e_i=0) = \sigma + (1-\sigma)p_0$, $\forall\, e_j$ and d_i, $i \neq j$.

The principal wants to induce $e_i=1$, $i=1, 2$, as the tasks are sufficiently valuable to her. Also, agent i's wages depend on both tasks' outcomes. It is assumed that all wages must be non-negative due to the limited liability of the agents, and each agent's reservation utility is zero.[43] The principal and both agents are assumed to be risk neutral. Let $w^i_{xi\,xj}$, $i \neq$

[40](...continued)
teach actively in a given semester. That is, teaching itself can be separated from the contribution to the teaching improvement seminar.

[41] The case in which the cooperation decisions are separable from the work decisions is examined in section 4.3.

[42] The probabilities of task i's success and failure given the work and cooperation decisions will be defined and used for the analysis instead of defining the random state of nature.

[43] Limited liability is not uncommon in practice. For example, in many
(continued...)

j, be the wage for agent i if $x_i \in \{0, 1\}$ and $x_j \in \{0, 1\}$. Since the agents' environments are symmetric, I will suppress superscripts.

4.2.2 Optimal contracts

In this section, the effects of inseparable-cooperation opportunities on compensation schemes are examined. Since it is assumed the principal wants to induce both agents to work, her problem is simply the minimization of the expected costs:

$$Min_{[w_{11},w_{10},w_{01},w_{00}]} \; C=2[(\sigma+(1-\sigma)(p_1+\varepsilon)^2)w_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)w_{10} + (1-\sigma)(1-p_1-\varepsilon)(p_1+\varepsilon)w_{01} + (1-\sigma)(1-p_1-\varepsilon)^2 w_{00}]$$

subject to

$$(\sigma+(1-\sigma)(p_1+\varepsilon)(p_1+\varepsilon))w_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)w_{10} + (1-\sigma)(1-p_1-\varepsilon)(p_1+\varepsilon)w_{01} + (1-\sigma)(1-p_1-\varepsilon)(1-p_1-\varepsilon)w_{00} \geq 0; \quad (4.1)$$

$$(\sigma+(1-\sigma)(p_1+\varepsilon)(p_1+\varepsilon))w_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)w_{10} + (1-\sigma)(1-p_1-\varepsilon)(p_1+\varepsilon)w_{01} + (1-\sigma)(1-p_1-\varepsilon)(1-p_1-\varepsilon)w_{00} - e \geq (\sigma+(1-\sigma)p_1p_1)w_{11} + (1-\sigma)p_1(1-p_1)w_{10} + (1-\sigma)(1-p_1)p_1w_{01} + (1-\sigma)(1-p_1)(1-p_1)w_{00} - e; \quad (4.2)$$

$$(\sigma+(1-\sigma)(p_1+\varepsilon)(p_1+\varepsilon))w_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)w_{10} + (1-\sigma)(1-p_1-\varepsilon)(p_1+\varepsilon)w_{01} + (1-\sigma)(1-p_1-\varepsilon)(1-p_1-\varepsilon)w_{00} - e$$

---

[43](...continued)
circumstances the maximum penalty a principal can impose on an agent is to simply fire the agent. Limited liability is supported and discussed by several researchers (for example, Sappington, 1983 and 1991; Milgrom, 1988; Baiman, May, and Mukherji, 1990; and Cremer, 1995).

$$\geq (\sigma+(1-\sigma)p_0p_1)w_{11} + (1-\sigma)p_0(1-p_1)w_{10} + (1-\sigma)(1-p_0)p_1w_{01} + (1-\sigma)(1-p_0)(1-p_1)w_{00}; \quad (4.3)$$

$$w^i_{xi\,xj} \geq 0,\ i = 1, 2,\ j = 1, 2,\ i \neq j,\ x_i \in \{0, 1\}, \text{ and } x_j \in \{0, 1\}. \quad (4.4)$$

Equation (4.1) denotes agent i's individual rationality constraint. There are two incentive compatibility constraints for each agent. Equation (4.2) implies that 'cooperation and work' is weakly better for agent i than 'noncooperation and work'. Hence, it represents agent i's cooperation-related incentive compatibility constraint. Equation (4.3) implies that 'cooperation and work' is weakly better for agent i than 'cooperation and shirk'. Hence, it represents agent i's work-related incentive compatibility constraints. Since the benefits of cooperation cannot be realized without working, the results of the 'noncooperation and shirk' decision are the same as those of the 'cooperation and shirk'. Finally, equation (4.4) represents both agents' limited liability constraints.

Since the left-hand side of equation (4.1) is always non-negative due to the limited liability constraints, both agents' individual rationality constraints are not binding. Moreover, it is not optimal if the principal rewards agent i for agent i's failure.[44] Hence, the principal's problem can be rewritten as follows:

$$Min_{[w_{11}, w_{10}]}\ C = 2[(\sigma+(1-\sigma)(p_1+\varepsilon)^2)w_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)w_{10}]$$

subject to

[44] This fact is summarized and proved in lemma 4.1.

$w^{i}_{xi\,xj} \geq 0, i = 1, 2, j = 1, 2, i \neq j, x_i \in \{0, 1\}$, and $x_j \in \{0, 1\}$; (4.4)

$((p_1+\varepsilon)^2 - p_1^2)\, w_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_1(1-p_1))\, w_{10} \geq 0$; (4.5)

$((p_1+\varepsilon)^2 - p_0 p_1)\, w_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))\, w_{10} \geq e/(1-\sigma)$. (4.6)

Equation (4.5) denotes agent i's cooperation-related incentive compatibility constraint. Equation (4.6) represents agent i's work-related incentive compatibility constraint. The optimal contract for agent i can be one of the following three wage schemes:

(W1) $w_{11} > 0$, and $w_{10} = 0$;

(W2) $w_{11} = 0$, and $w_{10} > 0$;

(W3) $w_{11} > 0$, and $w_{10} > 0$.

First, if the contract form (W1) is optimal, then the binding work-related incentive constraint implies

$w_{11} = e \,/\, [(1-\sigma)((p_1+\varepsilon)^2 - p_0 p_1)]$ and $w_{10} = 0$. (4.7)

This incentive system trivially satisfies cooperation-related constraint (4.5) because $((p_1+\varepsilon)^2 - p_1^2)\, w_{11} > 0$. Since the principal rewards the agents only if both agents' tasks are successful under this incentive system,[45] this system is defined as "*joint*" performance evaluation (JPE hereafter). Under JPE, the agents are always cooperative if the agents decide to work. The value of JPE, given cooperation opportunities, is JPE's ability to direct the agents' attention to both tasks' success and, therefore, to induce cooperation.

---

[45] The wages in the other situations are zero since the model normalizes to zero limited liability. If limited liability is greater than zero, an agent is paid positive wages (e.g., base salary) for any production outcomes and additional rewards (e.g., bonus) for the case in which both tasks succeed.

Second, if the contract form (W2) is the optimal form of wage contract, the binding work-related incentive constraint implies

$$w_{11} = 0 \text{ and } w_{10} = e / [(1-\sigma)((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))]. \quad (4.8)$$

Since it implies that an agent will be rewarded only if his task succeeds and the other agent's task fails, this incentive system is interpreted as "tournament-based" relative performance evaluation (TRPE hereafter). This incentive scheme satisfies cooperation-related constraint (4.5) if and only if $\varepsilon \leq 1-2p_1$.[46] If $\varepsilon > 1-2p_1$, then "noncooperation and work" is better than "cooperation and work" under the TRPE scheme. Cooperation increases not only the probability of the one's own success, but the other's success, as well. Under the TRPE scheme, the agent strives to increase the probability of his own success, but not to increase the probability of the other's success. Intuitively, if the benefits of cooperation are sufficiently great under the TRPE scheme, then the agent's incentive for his own success is dominated by his disincentive for the other agent's success. In this model, $1-2p_1$ is the critical value above which it is impossible for TRPE to induce cooperation due to the dysfunctional aspect of TRPE.

[46] Note that $\varepsilon > 1-2p_1$ implies that $(p_1+\varepsilon)(1-p_1-\varepsilon) - p_1(1-p_1) < 0$. In this case, constraint (5) cannot be satisfied under TRPE since the left-hand side of constraint (5) is strictly negative under TRPE if $\varepsilon > 1-2p_1$.

Finally, the contract form (W3) is examined. It is not difficult to see that the principal chooses (W3) if and only if $\varepsilon > 1\text{-}2p_1$ because of the linearity of the problem.[47] If $\varepsilon > 1\text{-}p_1$, $w_{11} > 0$, and $w_{10} > 0$, then equations (4.5) and (4.6) are binding, and

$$w_{11} = (\varepsilon - (1-2p_1))e \,/\, [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)]; \qquad (4.9)$$

$$w_{10} = (2p_1+\varepsilon)e \,/\, [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)]. \qquad (4.10)$$

The difference between w_{11} and w_{10} is

$$w_{11} - w_{10} = -e \,/\, (1-\sigma)(p_1-p_0)(p_1+\varepsilon). \qquad (4.11)$$

This contract implies that the principal pays a base reward $(\varepsilon - (1-2p_1))e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)]$, and an additional bonus, $e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)]$. The base reward is earned if the agent succeeds in his task, and the additional bonus is earned only if the agent succeeds and the other agent fails. Hence, this contract is characterized as "*bonus-based*" relative performance evaluation (BRPE). The principal should use BRPE because TRPE cannot induce cooperation for $\varepsilon \in (1\text{-}2p_1, 1\text{-}p_1)$. By paying the base salary for the agent's success in his own task, the principal provides enough incentive for cooperation. In addition, by paying bonuses for relative success, the principal can utilize information about the common environmental shock σ.

It is noteworthy that JPE is a team-oriented performance evaluation system because it makes both agents mutually accountable for the outcomes of both tasks.[48] Conversely,

---

[47] Note that $((p_1+\varepsilon)(1-p_1-\varepsilon) - p_1(1-p_1))w_{10}$ in constraint (4.5) is non-negative only if $\varepsilon \leq 1\text{-}2p_1$. If $\varepsilon \leq 1\text{-}2p_1$, then the only binding constraint is work-related incentive constraint (4.6). In this case, the principal never chooses to mix (W1) and (W2) since the principal's problem is linear.

[48] Chapter 2 discusses the importance of mutual accountability in defining "teams."

both TRPE and BRPE are competition-oriented performance measurement systems because an agent is rewarded when he outperforms another agent. Furthermore, the agents under these competition-oriented performance evaluation systems cannot be seen as the members of a team since they do not share performance goals for which they are mutually accountable.

Let C_J, C_{TR}, and C_{BR} be the agent *i*'s expected wages (which are the expected costs for the principal) under JPE, TRPE, and BRPE, respectively. Then, the following lemma characterizes the feasible incentive contracts in the inseparable-cooperation case.

Lemma 4.1: *Suppose the cooperation and work decisions are inseparable. Then, under the optimal incentive contract,* $w_{01} = w_{00} = 0$. *Furthermore, the optimal incentive contract is one of the following three contracts:*

(1) JPE for $\varepsilon \in (0, 1\text{-}p_1)$:

$$w_{11} = e / [(1-\sigma)((p_1+\varepsilon)^2 - p_0 p_1)];$$

$$w_{10} = 0;$$

$$C_J = (\sigma + (1-\sigma)(p_1+\varepsilon)^2)e / [(1-\sigma)((p_1+\varepsilon)^2 - p_0 p_1)].$$

(2) TRPE for $\varepsilon \in (0, 1\text{-}2p_1]$:

$$w_{10} = e / [(1-\sigma)((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))];$$

$$w_{11} = 0;$$

$$C_{TR} = (p_1+\varepsilon)(1-p_1-\varepsilon))e / [((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))].$$

(3) BRPE for $\varepsilon \in [1\text{-}2p_1, 1\text{-}p_1)$:

$$w_{11} = (\varepsilon - (1-2p_1))e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)];$$

$w_{10} = (2p_1 + \varepsilon)e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)];$

$C_{BR} = (\sigma(\varepsilon - (1-2p_1)) + (1-\sigma)p_1(p_1+\varepsilon))e / (1-\sigma)(p_1-p_0)(p_1+\varepsilon).$

Proof: See appendix 2.

If $\varepsilon > 1-2p_1$, then only (W1) and (W3) are possible. If $\varepsilon \in (0, 1-2p_1]$, (W1) and (W2) are possible. However, comparisons between C_J, C_{BR}, and C_{TR} reveal that the expected costs for the principal are lower under JPE than under either BRPE or TRPE if and only if

$$\sigma < \sigma^* = \varepsilon p_0(\varepsilon+p_1) / ((\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon)), \quad (4.12)$$

where $\sigma^* > 0$.

Proposition 4.1: *Suppose the cooperation and work decisions are inseparable. (1) If $\sigma < \sigma^*$, JPE is optimal for all $\varepsilon \in (0, 1-p_1)$. (2) If $\sigma \geq \sigma^*$, BRPE is optimal for $\varepsilon \in (Max\{0, 1-2p_1\}, 1-p_1)$ and TRPE is optimal for $\varepsilon \in (0, Max\{0, 1-2p_1\}]$.*

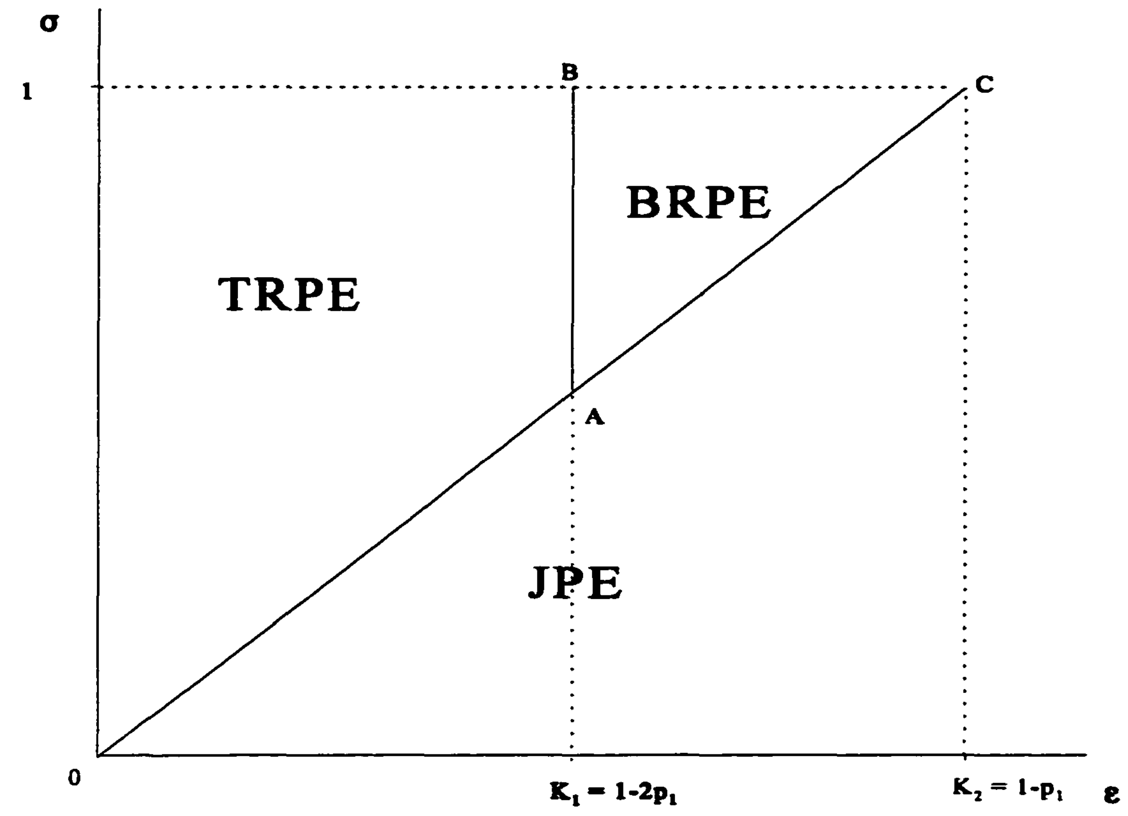
Proof: See appendix 2.

Proposition 4.1 states that team-oriented performance evaluation (i.e., JPE) is valuable if the effects of the common environmental factor are less than the critical value σ^*. The benefits of team-oriented performance evaluation stem from its ability to direct an agent to the success of other agents and to provide a clear incentive for cooperation. In contrast, the benefits of competition-oriented performance evaluation (i.e., TRPE or BRPE) stem from its ability to inform the principal about the common environmental factor and to reduce the moral hazard problem. An agent, however, may not cooperate under competitive performance evaluation even though cooperation benefits his own performance since, under competitive performance evaluation, cooperation may decrease the agent's expected rewards by increasing the other agent's performance as well as his own. Since the agent has an incentive to decrease, or at least not increase the other agent's performance under competitive performance evaluation, the principal must increase the rewards to compensate this negative effect of competitive performance evaluation on cooperation. This is true even if I assume that there are no additional efforts associated with cooperation and the effects of cooperation on each agent's performance are the same.

Therefore, competitive performance evaluation becomes less efficient in inducing cooperation than team-oriented performance evaluation as the benefits of cooperation increase or the benefits of reducing moral hazard problem associated with the common environmental factors decrease. Furthermore, even in situations where team-oriented performance evaluation is not optimal, the significant benefits of cooperation may limit the use of extreme competition (i.e., TRPE) because a tournament clearly decreases the incentive to cooperate. TRPE is efficient only if the benefit of cooperation is significantly low or information about the common environmental factor is significantly valuable.

Figure 4-2 illustrates proposition 4.1. The vertical axis measures the effects of the common environmental shock, σ, and the horizontal axis measures the benefits of cooperation, ε. The line *0C* represents σ^* given a specific ε. Hence, if $\sigma < \sigma^*$ for a specific ε, then JPE is the dominant incentive scheme. The area $0CK_2$ defines the area in which JPE dominates TRPE and BRPE. Similarly, the areas *0AB1* and *ABC* denote the areas in which TRPE and BRPE are the dominant incentive schemes, respectively. If $\varepsilon = 1\text{-}2p_1$,

Figure 4-2: Optimal Contracts (Inseparable Decisions)†



† Figure 4-2 depicts situations in which $0 < 1\text{-}2p_1$, or equivalently, $p_1 < 0.5$. For a given ε, the line *0C* represents $\sigma^* = \varepsilon p_0(\varepsilon+p_1) / ((\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon)$.

then TRPE and BRPE is indifferent. From figure 4-2, it is clear that the region in which JPE is optimal increases as the effects of the common environmental shock decrease or the benefits of cooperation increase. Moreover, figure 4-2 shows that σ^* (represented by the line *0C*) increases as ε increases. The following proposition summarizes this fact and other comparative statics with respect to σ^*.

Proposition 4.2: (1) $\partial\sigma^* / \partial\varepsilon > 0$.

(2) $\partial\sigma^* / \partial p_0 > 0$.

(3) $\partial\sigma^* / \partial p_1 < 0$ *iff* $\varepsilon < \frac{1}{2}(p_0 - 2p_1 + (p_0(4+p_0-4p_1))^{\frac{1}{2}})$.

Proof: See appendix 2.

The first result is intuitive. It states that as the benefits of cooperation increase, the critical value σ^* increases and, therefore, the region in which JPE dominates either TRPE or BRPE increases. The other two results require some explanation.

The second result implies that the area in which JPE dominates the other schemes (the area $0CK_2$ in figure 4-2) increases as p_0 increases. That is, the critical value increases as the probability of success, given shirking, increases. If the probability of success, given shirking, is low, then inducing "work" is very inexpensive for the principal. For example, consider the case that $p_0 = 0$. In this case, shirking behaviors result in no wages since the tasks cannot be successful without working. Therefore, the principal tries to minimize the expected costs by identifying the effects of the common shock. If she uses JPE, then she eventually ends up with payments for the common environmental shock as well as the effort. For example, if $p_0 = 0$, the expected costs under JPE are $e + [\sigma e / ((1-\sigma)(p_1+\varepsilon)^2)]$, whereas the expected costs under TRPE are e. Indeed, JPE is always dominated by either TRPE or BRPE if $p_0 = 0$. Therefore, if the probability of success, given shirking, is low, then the effect of the common environmental shock becomes an important factor in determining the optimal incentive scheme. Thus, RPE (i.e., either TRPE or BRPE) becomes a more attractive option than JPE. In contrast, if the probability of success, given shirking, is high, then the difference between working and shirking decreases. For example, if $p_0 \approx p_1$, then it is expensive to induce working because it is difficult to distinguish between working and shirking. In this case, inducing cooperation can be an inexpensive way to induce working, especially because the benefits of cooperation cannot be realized without working. Therefore, as the probability of success, given shirking, increases, the relative importance of cooperation increases. As a result, the area $0CK_2$ in figure 4-2, in which JPE dominates, increases as the probability of success given shirking, p_0, increases.

The final result reveals the interaction between p_1 and ε. If ε is sufficiently low, the final result implies that the region in which JPE dominates the other schemes decreases as p_1 increases. This is similar to the previous result with respect to p_0. That is, the relative importance of information about the common environmental shock increases as the probability of success given working increases. In other words, the benefits of JPE increase as the probability of success given working decreases. As a result, the area $0CK_2$ in figure 4-2, in which JPE dominates, increases as the probability of success given working, p_1, decreases if ε is sufficiently low.

If the benefits of cooperation, ε, are sufficiently high, however, increases in p_1 increase the region in which JPE dominates the other schemes. This can be explained by an examination of equation (4.6). If ε is high enough, the coefficient of w_{10} in equation (4.6) (i.e., $(p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1)$), becomes negative.[49] If the coefficient is negative, then the increases in w_{10} require increases in w_{11}, and decrease the value of the RPE schemes. Moreover, the coefficient of w_{10} in equation (4.6) decreases as p_1 increases if ε is high enough. If ε is great enough, then the benefits of cooperation are large, whereas the value of RPE decreases as p_1 increases. As a result, the area OCK_2 in figure 4-2, in which JPE dominates, increases as the probability of success given working, p_1, increases if ε is sufficiently high.

Overall, the region in which team-oriented performance evaluation (i.e., JPE) is optimal (the area OCK_2 in figure 4-2) increases as (1) p_0 increases, (2) p_1 increases with sufficiently high ε, or (3) p_1 decreases with sufficiently low ε. If ε is sufficiently low, the area in which team-oriented performance evaluation is optimal increases as the productivity increase arises from the "work" decision, which can be defined as $p_1 - p_0$, decreases. Conversely, if ε is sufficiently high, increases in p_0 or p_1 increase the area in which team-oriented performance evaluation is optimal since any competition-oriented performance evaluation scheme (i.e., BRPE or TRPE) becomes relatively more costly.

---

[49] A negative coefficient implies that TRPE cannot induce the agents to work.

4.3 Separation of Cooperation Decision and Work Decision

In the previous section, it is assumed that the agents cannot be "cooperative" if they shirk. It is possible, however, that the cooperation and work decisions can be separated and, therefore, the agents can be cooperative even though they shirk. This section examines the situation where it is possible for an agent to enjoy the benefits of cooperation if both agents decide to cooperate regardless of the other agent's work decision. Let $\lambda \in [0, 1]$ represent the degree of separation between the cooperation decision and the work decision. In other words, λ represents the fraction of the benefits of cooperation realized by an agent if both agents cooperate but the other agent decides to shirk. For example, if both agents cooperate but only agent 2 decides to work, the probability of task 2's success is $p_1+\lambda\varepsilon$, while the probability of task 1's success is p_0.[50] Let $s_{x_i x_j}$ be the wage for agent i if cooperation and work decisions are separable, where $i \neq j$, $x_i \in \{0, 1\}$ and $x_j \in \{0, 1\}$. Since s_{01} and s_{00} are zero under the optimal contract, the separable-cooperation opportunity changes the principal's problem to the following:[51]

$$Min_{[s_{11},s_{10}]} \; Z = 2[(\sigma+(1-\sigma)(p_1+\varepsilon)(p_1+\varepsilon))s_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)s_{10}]$$

subject to

$$((p_1+\varepsilon)^2 - p_1^2)\, s_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_1(1-p_1))\, s_{10} \geq 0; \qquad (4.13)$$

[50] The inseparable case examined in the previous section is a special case where $\lambda = 0$.

[51] The complete principal's problem with s_{01} and s_{00} is specified and analyzed in the proof of lemma 4.2.

$$((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))\, s_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1-\lambda\varepsilon))\, s_{10} \geq e/(1-\sigma); \quad (4.14)$$

$$((p_1+\varepsilon)^2 - p_0p_1)\, s_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))\, s_{10} \geq e/(1-\sigma); \quad (4.15)$$

$$s_{11} \geq 0,\, s_{10} \geq 0. \quad (4.16)$$

Equations (4.13), (4.14), and (4.15) are all incentive compatibility constraints.[52] First, equation (4.13) implies that "work and cooperation" is better than "work and noncooperation" for agent *i*, while the second equation (4.14) implies that "work and cooperation" is better than "shirk and cooperation" for agent *i*. Equation (4.15) guarantees that "work and cooperation" is better than "shirk and noncooperation." Equation (4.16) is the limited liability constraint.

In the previous inseparable-cooperation case, the agents cannot be cooperative if either agent shirks. Unlike the previous case, equation (4.14) is added because the agents can be cooperative regardless of the work decision.[53] This additional constraint is important because it increases the expected costs of using JPE and, therefore, decreases the value of JPE. Furthermore, adding equation (4.14) results in an additional feasible incentive scheme under which the principal pays the agent if the agent's task succeeds regardless of the other agent's performance. This contract scheme is defined as "*independent performance evaluation*" (IPE hereafter). Let Z_J, Z_{IPE}, Z_{TR}, and Z_{BR} be agent *i*'s expected wages (which are the expected costs for the principal) under JPE, IPE, TRPE,

[52] The individual compatibility condition is satisfied trivially due to the limited liability constraint.

[53] Note that in the previous case, equation (4.14) is the same as equation (4.15).

and BRPE, respectively. Then, the following lemma characterizes the feasible incentive contracts in the separable-cooperation case.

Lemma 4.2: *Suppose the cooperation and work decisions are separable. Then, under the optimal incentive contract,* $s_{01} = s_{00} = 0$. *Furthermore, the optimal incentive contract is one of the following four contracts.*

(1) JPE for $\varepsilon \in (0, 1\text{-}p_1)$:

$$s_{11} = e / [(1-\sigma)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))];$$

$$s_{10} = 0;$$

$$Z_J = (\sigma + (1-\sigma)(p_1+\varepsilon)^2)e / [(1-\sigma)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))].$$

(2) IPE for $\varepsilon \in (0, 1\text{-}p_1)$:

$$s_{11} = s_{10} = e / [(1-\sigma)(p_1+\varepsilon-p_0)];$$

$$Z_{IPE} = (\sigma+(1-\sigma)(p_1+\varepsilon))e / [(1-\sigma)(p_1+\varepsilon-p_0)].$$

(2) TRPE for $\varepsilon \in (0, 1\text{-}2p_1]$:

$$s_{11} = 0;$$

$$s_{10} = e / [(1-\sigma)((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))];$$

$$Z_{TR} = (p_1+\varepsilon)(1-p_1-\varepsilon))e / [((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))].$$

(4) BRPE for $\varepsilon \in [1\text{-}2p_1, 1\text{-}p_1)$:

$$s_{11} = (\varepsilon-(1-2p_1))e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)];$$

$$s_{10} = (2p_1+\varepsilon)e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)];$$

$$Z_{BR} = (\sigma(\varepsilon-(1-2p_1)) + (1-\sigma)p_1(p_1+\varepsilon))e / [(1-\sigma)(p_1-p_0)(p_1+\varepsilon)].$$

Proof: See appendix 2.

Lemma 4.2 shows that under JPE, $s_{11} = e / [((1-\sigma)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))]$, which is bigger than w_{11} defined in equation (4.7). Intuitively, the value of JPE stems from the fact that it motivates an agent to help the other agent succeed. If the cooperation decision cannot be separated from the work decision, the probability of the other agent's success increases only if the agent cooperates as well as works. If the cooperation decision can be separated from the work decision, however, that probability can be increased by cooperation with shirking. The informational value of JPE decreases more under the separable cooperation case than under the inseparable cooperation case and, therefore, JPE becomes a more expensive option for the principal. Moreover, the benefits of JPE in inducing cooperation decrease as the degree of separation (λ) increases.[54]

Lemma 4.2 also shows that there exists an alternative scheme, IPE, that can be used if the cooperation and work decisions are separable. A positive s_{10} (i.e., RPE) is valuable to extract information about the common environmental shock, whereas a positive s_{11} (i.e., JPE) is valuable to induce cooperation. Under IPE, the principal can induce the agent to work and cooperate by balancing these two countervailing effects.[55] The next proposition characterizes the relationship between JPE and IPE.

---

[54] Note that $\partial Z_J / \partial \lambda > 0$.

[55] A reason for $s_{11} = s_{10}$ is the assumption that cooperation does not require additional effort. If this assumption does not hold, the suggested scheme would neither be IPE nor simple JPE.

Proposition 4.3: *IPE dominates JPE if $\lambda > \lambda^*$, where*

$$\lambda^* = [\varepsilon p_0 (p_1+\varepsilon) - \sigma(1-p_1-\varepsilon)(p_1+\varepsilon-p_0-\varepsilon p_0)] / [\varepsilon p_0(\sigma+(1-\sigma)(p_1+\varepsilon))].$$

JPE dominates IPE if $\lambda < \lambda^*$.

Corollary 4.1: $\partial\lambda^* / \partial\sigma < 0$.

Proof: See appendix 2.

Proposition 4.3 states that IPE dominates JPE if $\lambda > \lambda^*$. JPE provides the agents not only an incentive for shirking but also an incentive for cooperation. Under JPE, an agent can increase his chance of receiving wages simply by cooperating and, therefore, increasing the other agent's probability of success.[56] Since shirking does not prevent this probability increase, JPE provides incentives for shirking while providing incentives for cooperation. It is clear that the opportunity for free-riding increases as λ increases. An option for preventing this type of free-riding behavior is RPE. RPE, however, may not provide enough incentive for cooperation since cooperation benefits the other agent. To balance these two conflicting incentives, the principal may use IPE. By using IPE, the principal can provide incentives for both working and cooperation. Specifically, IPE is an effective scheme to ameliorate JPE's free-riding problem. Since the free-riding problem under JPE increases as the degree of separation (λ) increases, IPE dominates JPE if λ is sufficiently large.

The corollary shows that as the effects of the common environmental shock (σ) increase, the critical value λ^* increases and, therefore, the range within which IPE

[56] This is true even if cooperation does require additional effort.

dominates JPE increases. The reason is intuitive. Both JPE and IPE compensate the agents even if the common environmental shock is favorable. However, the probability of paying non-zero wages under JPE is

$$\sigma + (1-\sigma)(p_1+\varepsilon)^2 = 1 + \sigma(1 - (p_1+\varepsilon)^2) \qquad (4.17)$$

while the probability of paying the wages under IPE is

$$\sigma + (1-\sigma)(p_1+\varepsilon) = 1 + \sigma(1 - (p_1+\varepsilon)). \qquad (4.18)$$

Since the favorable environmental shock does not require the agents' effort for success, the principal wants to avoid paying non-zero wages given the favorable environmental shock. Equations (4.17) and (4.18) show that the probability of paying non-zero wages is higher under JPE than under IPE by $\sigma(p_1+\varepsilon)(1-p_1-\varepsilon)$; this difference increases as σ increases. This relationship is confirmed by examining the condition in proposition 4.3. By rearranging the condition in proposition 4.3, it can be shown that IPE dominates JPE if $\sigma \geq \sigma^\lambda$, where

$$\sigma^\lambda = (1-\lambda)\varepsilon p_0(p_1+\varepsilon) / [(1-p_1-\varepsilon)(p_1+\varepsilon + \lambda\varepsilon p_0 - p_0 - \varepsilon p_0)] > \sigma^*.$$

Therefore, IPE dominates JPE if σ is sufficiently large.

RPE is useful in extracting information about the common environmental shock, but not useful in inducing cooperation. In contrast, JPE is useful in inducing cooperation while it is not useful in extracting information about the common environmental shock. IPE can be utilized to balance these two effects given the separable cooperation decision. The following proposition summarizes the results:

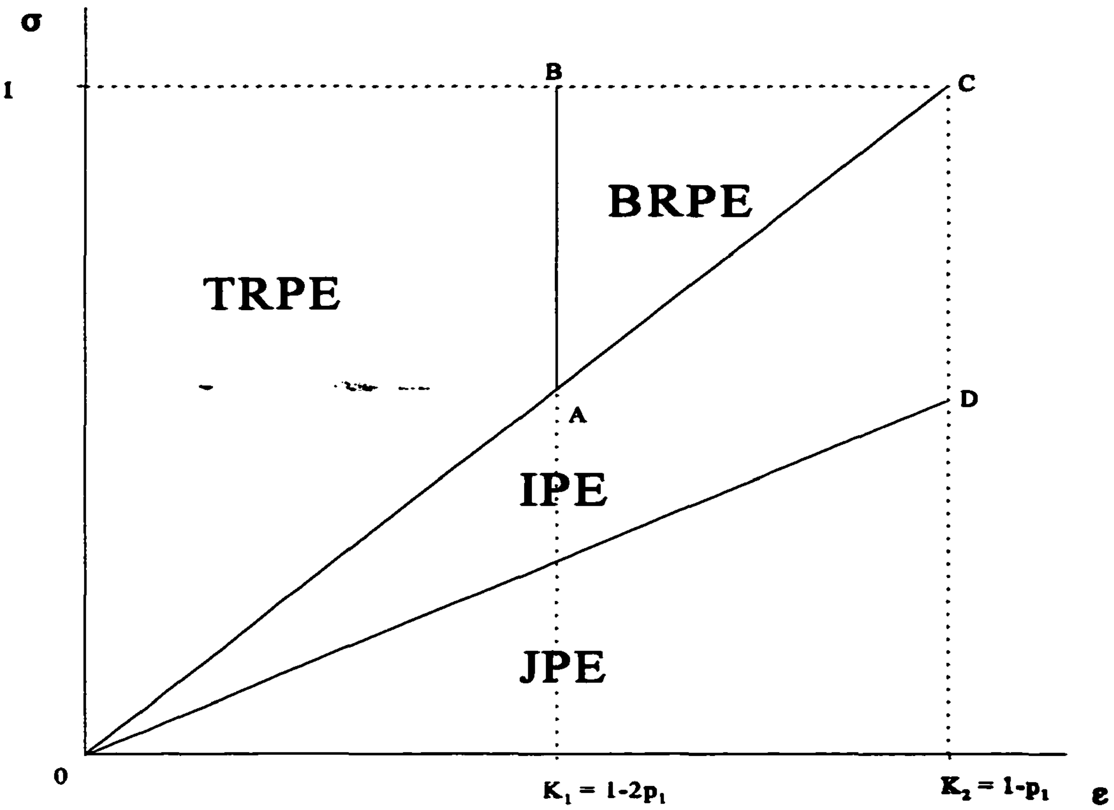
Proposition 4.4: *Suppose the cooperation and work decisions are separable. (1) If $\sigma < \sigma^{\lambda}$, JPE is optimal for all $\varepsilon \in (0, 1\text{-}p_1)$. (2) If $\sigma^{\lambda} \leq \sigma < \sigma^{*}$, IPE is optimal for all $\varepsilon \in (0, 1\text{-}p_1)$. (3) If $\sigma \geq \sigma^{*}$, BRPE is optimal for $\varepsilon \in (Max\{0, 1\text{-}2p_1\}, 1\text{-}p_1)$ and TRPE is optimal for $\varepsilon \in (0, Max\{0, 1\text{-}2p_1\}]$.*

Proof: See appendix 2.

Proposition 4.4 characterizes conditions under which JPE, IPE, BRPE, and TRPE are optimal. Suppose $\sigma < \sigma^{\lambda}$. Then, the effects of the common environmental shock on the task's success are not significant. In this case, cooperation is relatively important and, therefore, JPE is the optimal incentive contract. Now, suppose $\sigma \geq \sigma^{\lambda}$. Then, JPE is dominated by IPE since the effects of the common environmental shock are significant. In this case, only IPE, BRPE, and TRPE must be compared. If $\sigma \geq \sigma^{\lambda}$ and $\varepsilon > 1\text{-}2p_1$, then TRPE is not available, and IPE is optimal and dominates BRPE if and only if the effects of the common environmental shock are less that a critical value σ^{*}. Similarly, if $\sigma \geq \sigma^{\lambda}$ and $\varepsilon \leq 1\text{-}2p_1$ (hence BRPE is not available), then IPE is optimal and dominates TRPE if and only if the effects of the common environmental shock are less that a critical value σ^{*}. Also, the expected costs for the principal under BRPE and TRPE are the same if and only if $\sigma = 1\text{-}2p_1$.

Figure 4-3 illustrates proposition 4.4. The vertical axis measures the effects of the common environmental shock, σ, and the horizontal axis measures the benefits of cooperation, ε. To represent proposition 4.4, figure 4-3 is based on situations in which $0 < 1\text{-}2p_1$, or equivalently $p_1 < 0.5$. Hence, all of the schemes discussed in lemma 4.2 are

Figure 4-3: Optimal Contracts (Separable Decisions)†



† Figure 4-3 depicts situations in which $0 < 1\text{-}2p_1$, or equivalently, $p_1 < 0.5$. For a given ε, the lines *OC* and *OD* represent $\sigma^* = \varepsilon p_0(\varepsilon+p_1) / ((\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon)$ and $\sigma^\lambda = (1-\lambda)\varepsilon p_0(p_1+\varepsilon) / [(1-p_1-\varepsilon)(p_1+\varepsilon+\lambda\varepsilon p_0-p_0-\varepsilon p_0)]$, respectively.

possible for some range of ε. Specifically, if $0 < \varepsilon < 1\text{-}2p_1$, then IPE, JPE, and TRPE are available schemes. If $1\text{-}2p_1 < \varepsilon < 1\text{-}p_1$, then IPE, JPE, and BRPE are available. The line *0C* represents σ^* and the line *0D* represents σ^λ.

Figure 4-3 shows that JPE is the optimal incentive contract if $\sigma < \sigma^\lambda$ for an $\varepsilon \in (0, 1\text{-}p_1)$. The area *0DK*$_2$ defines the area in which JPE dominates the other incentive contracts. Similarly, IPE is the optimal incentive contract if $\sigma^\lambda \leq \sigma < \sigma^*$ for an $\varepsilon \in (0, 1\text{-}p_1)$. The area *0CD* defines the area in which IPE dominates the other incentive contracts. If $\sigma > \sigma^*$ for an $\varepsilon \in (0, 1\text{-}2p_1]$, then TRPE is the optimal incentive contract, and the area *0AB1* denotes the area in which TRPE dominates. Finally, if $\sigma > \sigma^*$ for an $\varepsilon \in (1\text{-}2p_1, 1\text{-}p_1)$, then BRPE is the optimal incentive contract and its area is defined as *ABC*. From figure 4-3, it is clear that the regions in which JPE and IPE are optimal increase as the effects of the common environmental shock decrease.

Moreover, in the separable case, the region in which JPE is the optimal incentive contract increases as the degree of separation (λ) decreases.[57] Therefore, there exists an inverse relationship between the benefits of team-oriented performance evaluation (i.e., JPE) and the separability of the benefits of cooperation and the work decision. Team-oriented performance evaluation provides an incentive for shirking while providing an incentive for cooperation. The negative effects of team-oriented performance evaluation decrease as a cooperation decision and a work decision become more inseparable. Since inseparable cooperation implies that the realization of the benefits of cooperation depends on the agents' work decisions, the principal, using the team-oriented performance

---

[57] Note that $\partial\sigma^\lambda / \partial\lambda < 0$.

evaluation system, can reinforce the agents' incentives to work by providing incentives to cooperate. Hence, the degree of separation is an important determinant of the optimality of team-oriented performance evaluation.

4.4 Conclusion

This chapter examines the characteristics of various compensation contracts and the conditions under which the benefits of cooperation can be efficiently realized. Specifically, this chapter compares the benefits of team-oriented performance evaluation, competitive performance evaluation, and independent performance evaluation. Although Itoh (1991, 1992) and Hemmer (1995) study the implications of a helping effort on optimal performance evaluation systems, the results in this chapter provide new insights into the interactions among performance evaluation systems, task characteristics, and task relationships.

First, by introducing the concept of cooperation into the model, this chapter shows the benefits of team-oriented performance evaluation even if there exist common environmental shocks. As Holmstrom (1982) and Mookherjee (1984) show, competition-oriented relative performance evaluation is valuable if the agents face common uncertainty under which an agent's output provides information about another agent's state of nature. In contrast, Itoh (1991, 1992) and Hemmer (1995) examine cases in which each agent can provide the other agent a helping effort, which is not necessarily to increase his own performance, and show conditions under which team-oriented performance evaluation and task allocations are optimal.

The analysis in this chapter, however, demonstrates that an agent may not cooperate under competitive performance evaluation (i.e., TRPE or BRPE) even though cooperation benefits his own performance. For example, under TRPE, the principal rewards an agent only if his task succeeds and the other agent's task fails. Under this extremely competition-oriented system, an agent may give up possible increases in his own performance and decide not to cooperate to prevent increases in the other agent's performance since the agent has an incentive to decrease, or at least not increase, the other agent's performance. As the benefits of cooperation increase, these negative effects of TRPE increase and, therefore, TRPE becomes a sub-optimal performance evaluation system. An alternative to TRPE is BRPE, under which a base reward is earned if the agent succeeds in his task, and an additional bonus is earned only if the agent succeeds and the other agent fails. Although BRPE mitigates the competitive elements of TRPE by rewarding the agent's success regardless of the other agent's performance, it still relies on competition between the agents and, therefore, results in the same problem as TRPE if the benefits of cooperation are significantly large. As a result, if the effects of cooperation are significantly large, team-oriented performance evaluation is used in the following way: the principal has an agent responsible for the success of both his and the other agent's tasks (i.e., JPE). The benefits of this team-oriented performance evaluation system stem from its ability to direct agents to the success of others and to provide a clear incentive for cooperation. As the benefits of cooperation increase, cooperation is more efficiently induced by team-oriented performance evaluation than by competitive performance evaluation.

Second, this chapter examines the implications of the relationships between cooperation and productive work on optimal performance evaluation systems. Specifically, the model treats the degree of separation between the benefits of cooperation and the work decision as endogenous. The relationship between the benefits of cooperation and the work decisions is defined as "*inseparable*" if the benefits of the employees' simultaneous cooperation decisions are not realized without work efforts. In contrast, the relationship is defined as "*separable*" if the benefits of the employees' simultaneous cooperation decisions can be realized without work efforts. The analysis shows that, as the relationships become more separable, team-oriented performance evaluation provides the agents with not only more incentive for cooperation, but more incentive for shirking as well. Another option for preventing such free-riding behavior is competitive performance evaluation. Competitive performance evaluation, however, may not provide enough incentive for cooperation since cooperation benefits the other agent. To balance these two conflicting incentives, the principal utilizes independent performance evaluation (IPE), under which an agent is rewarded for his task's success regardless of the other agent's performance. By employing IPE, the principal can provide appropriate incentives for both working and cooperation. Furthermore, the results show that there exists an inverse (positive) relationship between the benefits of team-oriented (independent) performance evaluation and the separability of a cooperation decision and a work decision.

Throughout this chapter, cooperation opportunities are assumed as given and their effects on performance evaluation systems are examined; future research might treat them as endogenous. Furthermore, future research might examine organizational, technological or behavioral conditions under which those cooperation opportunities arise and examine the interactions between those conditions and performance evaluation systems. For example, Just-In-Time, Flexible Manufacturing Systems (FMS), and lean production change manufacturing processes and relationships among agents. As a result, understanding interactions between those changes and performance measurement systems/organizational structures becomes important in business success.

Chapter 5. The Nature of Tasks and Incentive Contracts

5.1 Introduction

As I show in chapters 3 and 4, the possibilities of cooperation and externalities existing among agents determine the effectiveness of team-oriented organizational structures and performance measurement. Specifically, in chapter 3, I show that an individual information system can be undesirable if there exists an opportunity for an agent's adaptive decision making due to externalities after information is revealed. In chapter 4, I show that the relationships between cooperation and work decisions determine the effectiveness of team-oriented incentive contracts (e.g., JPE). These two chapters not only derive some important conditions under which team-oriented incentive contracts and information systems are beneficial, but also imply that the nature of and relationships among agents' tasks can be important determinants of the benefits of team-oriented incentive contracts.

The purpose of this chapter is to further examine the effects of the nature of tasks on incentive contracts. Specifically, I examine situations where (i) an agent's effort affects both his and the other agent's performance in sequential production and (ii) both agents are engaged in problem-solving activities. First, I show that the form of an agent's optimal incentive contract depends on the effect of the agent's effort on performance measures, especially if an agent's performance measure signals both his and the other agent's performance. Specifically, I examine the situation where the first agent can affect the outcome of the second task while the second agent cannot affect the outcome of the first task. Under the optimal incentive contract, the first agent's reward increases as the second agent's performance increases, as well as his own performance increases. The second agent's reward, however, increases as his own performance increases, but decreases as the first agent's performance increases even though no common shock is associated with the agents' tasks. Unlike the literature examining the effects of common shocks (for example, Holmstrom, 1982; Mookherjee, 1984), RPE is used for the second agent's performance evaluation to distinguish the second agent's contribution from the first agent's contribution to the outcome of the second task.

Second, I examine the effects of agents' problem-solving activities on incentive contracts. It is assumed that two agents are engaged in a problem-solving activity and its result can improve the outcomes of their production tasks. Moreover, it is assumed that the principal can subjectively predict the effectiveness of the outcomes of the problem-solving task on production. The real litmus test of its effectiveness, however, is the improvement in the outcomes of production tasks. Therefore, the outcomes of production tasks provide additional information about the effectiveness of the agent's problem-solving effort. In this case, a team-oriented incentive contract (i.e., JPE) with respect to production tasks can be used to motivate the agents to exercise proper problem-solving efforts when the agents are assigned to both problem-solving tasks and production tasks, and the errors associated with the principal's subjective assessment are sufficiently large. Although Itoh (1991, 1992) shows a similar result introducing the possibility of an agent's helping effort, his model can be viewed as a special case in which the principal cannot assess the effectiveness of problem-solving efforts and an agent's problem-solving effort improves the outcome of the other agent's task but does not improve the outcome of his task.

The following section examines incentive contracts in a sequential production setting using a continuous effort model. Sections 5.3 characterizes the effects of a problem-solving activity on incentive contracts. A brief conclusion is provided in section 5.4.

5.2 Performance Measurement in Sequential Production

In this section, I model a sequential production process, which is similar to the model in chapter 3, with worker specialization. An example of this type of process is an assembly line production process. It is assumed that there are two agents, agent 1 and 2, responsible for tasks 1 and 2, respectively. The outcome of task 1 is an intermediate product, whose value is determined by its quality, $x_1(e_1, \hat{\varepsilon}_0)$, where e_1 is the effort of agent 1 and $\hat{\varepsilon}_0$ is a random shock in production process 1. If a principal wants to evaluate x_1, then she can introduce an imperfect (quality) reporting system. The system reports $I_1(x_1, \hat{\varepsilon}_1)$, where $\hat{\varepsilon}_1$ is a random error in the inspection process. Therefore, the principal and the two agents can have an inspection report only after the production process is completed. The outcome of task 2 is a final product, whose value is determined by its quality, $x_2(e_2, x_1, \hat{\varepsilon}_2)$, where e_2 is the effort of agent 2 and $\hat{\varepsilon}_2$ is a random shock in production process 2. It is assumed that the principal sells x_2 to an external market, and the final product market evaluates the outcome (quality) with no error. The principal realizes revenue $R(x_2) = x_2$.

The outcomes and efforts are assumed continuous, and production functions are assumed as follows:

$$x_1 = e_1 + \hat{\varepsilon}_0, \quad (5.1)$$

$$I_1 = x_1 + \hat{\varepsilon}_1, \quad (5.2)$$

$$x_2 = e_2 + vx_1 + \hat{\varepsilon}_2, \quad (5.3)$$

where $\hat{\varepsilon}_j \sim N(0, \hat{\sigma}_j)$, $j = 0, 1, 2$, and v is an externality realized from the outcome (quality) of the intermediate product. The relationship between the two agents is defined in terms of x_2. That is, the first agent's effort increases the outcome of the final product, which combines both agents' efforts. It is assumed that $\hat{\varepsilon}_0$, $\hat{\varepsilon}_1$, and $\hat{\varepsilon}_2$ are independent.[58] Consequently, equations (5.2) and (5.3) can be rewritten as follows:

$$I_1 = e_1 + \hat{\varepsilon}_0 + \hat{\varepsilon}_1$$

$$= e_1 + \varepsilon_1, \quad (5.2')$$

$$x_2 = e_2 + v(e_1 + \hat{\varepsilon}_0) + \hat{\varepsilon}_2$$

$$= e_2 + ve_1 + \varepsilon_2, \quad (5.3')$$

where $\varepsilon_1 = \hat{\varepsilon}_0 + \hat{\varepsilon}_1 \sim N(0, \sigma_1)$, $\sigma_1^2 = \hat{\sigma}_0^2 + \hat{\sigma}_1^2$, and $\varepsilon_2 = v\,\hat{\varepsilon}_0 + \hat{\varepsilon}_2 \sim N(0, \sigma_2)$, $\sigma_2^2 = v^2\hat{\sigma}_0^2 + \hat{\sigma}_2^2$.

Each agent's utility function is described by an exponential function,

$$U_i(s_i - c(e_i)) = -\exp[-r(s_i - c(e_i))], \; i = 1, 2, \quad (5.4)$$

where $r > 0$ is the agent's absolute risk aversion, s_i is the agent's compensation schedule, and $c(e_i)$ is the agent's disutility function associated with the effort e_i. The compensation

---

[58] In other words, there are no common environmental shocks associated with the production process.

schedule is restricted to be a linear function of information about each agent's output, and $c(e_i) = \frac{1}{2}e_i^2$ for simplicity.[59] The compensation schedule is characterized by the following:

$$s_1 = a_0 + a_1 I_1 + a_2 x_2,$$

and

$$s_2 = b_0 + b_1 I_1 + b_2 x_2.$$

The incentive contract utilizes the inspection report and the outcome of the final product to compensate each agent. Therefore, both agents are evaluated and compensated based on the outcomes of both the intermediate product and the final product. Without loss of generality, the agent's opportunity wage is assumed to be zero. Then, the principal's problem can be rewritten as

$$\text{Max } EU_p = e_2 + ve_1 - E(s_1(I_{x1}, x_2)) - E(s_2(I_{x1}, x_2))$$

subject to

$$EU_i[s_i(I_{x1}, x_2), c(e_i)] \geq 0; \qquad (5.5)$$

$$e_i \in \text{argmax } EU_i[s_i(I_{x1}, x_2), c(e_i)], \text{ where } i = 1, 2. \qquad (5.6)$$

[59] Holmstrom and Milgrom (1987) examine a model under which a linear compensation schedule is optimal in a multi-period setting. As I assume in this chapter, they assume (i) exponential utility, and (ii) normal distributions of the error terms associated with performance measures. Furthermore, they assume the agent's controllability of the drift rate of a stochastic process of performance measures. Some single-period applications of their model can be found in Holmstrom and Milgrom (1990, 1991), Itoh (1992), and Hemmer (1995).

Constraint (5.5) represents the agents' individual rationality constraint, whereas constraint (5.6) represents their incentive compatibility constraints. The optimal solution for this principal's problem is summarized in the following lemma:

Lemma 5.1: *(i) The optimal solution for the above principal's problem is:*

$$e_1^* = [v(v^2\sigma_1^2 - 2v\sigma_{12} + \sigma_2^2)] / [v^2\sigma_1^2 - 2v\sigma_{12} + \sigma_2^2 - r\sigma_{12}^2 + r\sigma_1^2\sigma_2^2],$$

$$e_2^* = \sigma_1^2 / [\sigma_1^2 - r\sigma_{12} + r\sigma_1^2\sigma_2^2],$$

$$a_1^* = [v(\sigma_2^2 - v\sigma_{12})] / [v^2\sigma_1^2 - 2v\sigma_{12} + \sigma_2^2 - r\sigma_{12}^2 + r\sigma_1^2\sigma_2^2],$$

$$a_2^* = [v(v\sigma_1^2 - \sigma_{12})] / [v^2\sigma_1^2 - 2v\sigma_{12} + \sigma_2^2 - r\sigma_{12}^2 + r\sigma_1^2\sigma_2^2],$$

$$b_1^* = -[v(v^2\sigma_1^2 - 2v\sigma_{12} + \sigma_2^2)] / [v^2\sigma_1^2 - 2v\sigma_{12} + \sigma_2^2 - r\sigma_{12}^2 + r\sigma_1^2\sigma_2^2],$$

$$b_2^* = \sigma_1^2 / [\sigma_1^2 - r\sigma_{12} + r\sigma_1^2\sigma_2^2],$$

$$EU_p^* = ½(e_2^* + ve_1^*).$$

(ii) As v increases, e_1^* increases and e_2^* remains constant.

(iii) $a_1^* > 0$, $a_2^* > 0$, $b_1^* > 0$, and $b_2^* < 0$.

Proof: See appendix 3.

Lemma 5.1 shows that the first agent's effort increases as the externality, v, increases whereas the second agent's effort is constant. Since the principal's utility is determined by x_2, which is increasing in v, she wants to motivate the first agent to work hard as the externality increases. The principal, however, does not have any reason to change the second agent's incentive even though v changes. As a result, the incentive part of the first agent's wage (i.e., a_1 and a_2) increases as the externality increases, and therefore, the first agent increases effort accordingly. However, the second agent is not provided with that incentive in his compensation schedule, and hence, does not react to the changes in the externality.

This characteristic of the optimal incentive contract is described in the last part of lemma 5.1. Since the first agent is responsible for the outcome of the intermediate product and this outcome determines a part of the outcome of the final product, the principal, using information about both outcomes (i.e., I_1 and x_2), compensates the first agent positively with respect to both outcomes (i.e., $a_1^* > 0$ and $a_2^* > 0$). That is, the first agent's realized wage increases as either performance measure increases. In this case, the first agent's compensation based on the outcome of the final product can be viewed as a type of bonus which reinforces the incentive. The second agent's compensation schedule, however, shows $b_2^* < 0$. This resembles a RPE contract, but the reason behind this contract is different than that of other RPE systems examined in the literature. This result stems from the fact that part of the second agent's outcome is attributable to the outcome of the first task. Since the principal wants to distinguish the effects of the first agent's effort from those of the second agent's effort, she subtracts the effects of the outcome of the first task on the final outcome from the second agent's performance. Therefore, this result holds even if there is no common uncertainty (i.e., $\hat{\sigma}_{12} = 0$) although the advantage of RPE is often argued to be realized under the common uncertainty cases.

Furthermore, lemma 5.1 shows that an individual inspection system is always utilized to motivate both agents.[60] The reason is that, unlike the situation in chapter 3, there is no opportunity of agents' adaptive behaviors after information is delivered. In this case, the principal can have more information and more motivational tools by utilizing the individual inspection report. Because the individual inspection report reinforces the first agent's incentive by directly investigating the outcome of the intermediate product, it can induce better performance from the first agent. Furthermore, by using the inspection report, the principal can mitigate the information asymmetry problem underlying the final production process. The second agent's performance is more transparent given the individual inspection report because the report reveals information about the part of the final outcome contributed by the first agent. As a result, utilizing the individual inspection report motivates the second agent better for the principal in inducing both agents' efforts.

5.3 Problem-Solving Activities

Recently, problem-solving activities have become an important factor in improvement of productivity and product quality. For example, the success of total quality management teams and quality circles at Texas Instruments Malaysia can be, at least partially, attributed to team members' consistent efforts in solving quality-related problems at hand (Cheney, Sims, and Manz, 1993). Moreover, problem-solving teams are one of the

---

[60] If the principal does not want to utilize the individual inspection system, she will set $a_1 = b_1 = 0$, which is not optimal, as shown in lemma 5.1.

popular type of teams adopted by firms.[61] In this section, I examine the effects of problem-solving activities on incentive contracts using a model similar to the model in section 5.2.

It is assumed that there are two agents, agent 1 and 2, who take charge on tasks 1 and 2, respectively. At the beginning of the production process, both agents are assigned on a problem-solving task. The agents are asked to identify possible problems and find possible solutions for the problems. This report does not provide the principal with any direct profit, but it does provide a benefit by improving the performance of both agents' normal production tasks. The value of the problem-solving activity, which the principal is assumed not to directly observe, is

$$y_r(f_1, f_2) = f_1 + f_2,$$

where f_1 and f_2 is the effort of agent 1 and agent 2, respectively.[62] After solving the problems in their production process, each agent proceeds to perform his normal production task. The outcome of task i is

$$x_i(e_i, y_r, \varepsilon_i) = e_i + v\, y_r + \varepsilon_i, \qquad (5.7)$$

where e_i is the effort of agent i, $v \in (0, \infty)$ is the effect of agent j's problem-solving effort on performance of agent i's task, and $\varepsilon_i \sim N(0, \sigma)$ is a random shock in production process

[61] Dumain (1994) reports 91% of American firms use problem-solving teams.

[62] Although it is assumed that there is no uncertainty associated with problem-solving activities, relaxing this assumption does not change the results.

i.[63] Therefore, agent i's problem-solving effort improves the outcomes of both agent i and j's tasks by $v(f_1 + f_2)$.[64]

Although the principal cannot observe the agents' problem-solving efforts, it is assumed that the problem-solving activity can be reviewed by the principal and evaluated as

$$x_r(f_1, f_2\ \varepsilon_r) = f_1 + f_2 + \varepsilon_r, \tag{5.8}$$

where $\varepsilon_r \sim N(0, \sigma_r)$ is a random error in subjectively evaluating the problem-solving activity.[65] The covariance of ε_1 and ε_2 is assumed to be $\rho\sigma^2$ and the covariance of ε_r and ε_i is assumed to be zero.

Each agent's utility function is described by an exponential function,

$$U_i(s_i - c(e_i)) = -\exp[-r(s_i - c(e_i) - c(f_i))],\ i = 1, 2,$$

where $r > 0$ is the agent's absolute risk aversion, s_i is the agent's compensation schedule, and $c(e_i)$ and $c(f_i)$ are the agent's disutility function associated with the efforts. For simplicity, it is assumed that $c(e_i) = \frac{1}{2}e_i^2$ and $c(f_i) = \frac{1}{2}f_i^2$. The compensation schedule is

---

63 To save notation, I assume that the variance of the error terms of each performance measure is σ^2. The qualitative results do not change even if the variances are different.

64 The problem-solving tasks in this chapter and cooperation in chapter 4 have similar characteristics. Specifically, the agents' efforts for both tasks increase the agents' performance. While cooperation requires both agents' simultaneous efforts and its effects on both agents' performance are not directly measurable, however, the effects of an agent's problem-solving effort can be realized without the other agent's problem-solving effort and are measurable subjectively.

65 Itoh's (1992) model can be viewed as a special case in which x_r cannot be generated and $x_i = e_i + v\,y_r + \varepsilon_i$, where $y_r = f_j$, $i \neq j$.

restricted to be a linear function of information about each agent's output. The incentive contract is characterized by the following:[66]

$$s_1 = a_0 + a_r x_r + a_1 x_1 + a_2 x_2,$$

and

$$s_2 = b_0 + b_r x_r + b_1 x_1 + b_2 x_2.$$

The principal's problem in this case is:

$$\text{Max } EU_p = E(x_1+x_2) - E(s_1(x_r, x_1, x_2)) - E(s_2(x_r, x_1, x_2))$$

subject to

$$EU_i[s_i(x_r, x_1, x_2), c(f_i, e_i)] \geq 0; \quad (5.9)$$

$$e_i \in \text{argmax } EU_i[s_i(x_r, x_1, x_2), c(f_i, e_i)]; \quad (5.10)$$

$$f_i \in \text{argmax } EU_i[s_i(x_r, x_1, x_2), c(f_i, e_i)], \text{ where } i = 1, 2. \quad (5.11)$$

Constraint (5.9) in the principal's problem represents the agents' individual rationality constraint, whereas constraints (5.10) and (5.11) represent their incentive compatibility constraints with respect to problem-solving and production efforts, respectively. The optimal solution for this principal's problem is summarized in the following lemma:

---

[66] I assume that the principal's subjective evaluation is observable by the agents and contractible. Although this assumption is restrictive, the use of subjective evaluation on agents' performance is not uncommon. For example, informal reviews of a team or individual's performance by customers, clients, managers, and fellow team members are often included in the performance evaluation process (Eccles and Crane, 1988; Mohrman, Cohen, Mohrman Jr., 1995).

Lemma 5.2: ***Under the assumptions given above, the optimal solution for the above principal's problem is:***

$$e_1^* = e_2^* = [\sigma^2(1+r\sigma_r^2) + v^2\sigma_r^2(1+2r\sigma^2-2r\rho\sigma^2)] / \Phi,$$

$$f_1^* = f_2^* = v[\sigma^2(2+(2r\sigma^2+r\sigma_r^2)(1-\rho)) + v^2(2\sigma_r^2+4r\sigma^2\sigma_r^2)(1-\rho))] / \Phi,$$

$$a_1^* = b_2^* = [\sigma^2(1+r\sigma_r^2) + v^2\sigma_r^2(1+2r\sigma^2-2r\rho\sigma^2)] / \Phi,$$

$$a_2^* = b_1^* = [v^2\sigma_r^2(1+2r\sigma^2-2r\rho\sigma^2) - \rho\sigma^2(1+r\sigma_r^2)] / \Phi,$$

$$a_r^* = b_r^* = [v\sigma^2(1+\rho)(1+2r\sigma^2-2r\rho\sigma^2)] / \Phi,$$

$$EU_p^* = ½(x_1^* + x_2^*),$$

where $\Phi = \sigma^2(1+r\sigma_r^2)(1+r\sigma^2(1-\rho^2)) + v^2\sigma_r^2(1+2r\sigma^2(1-\rho))$.

Proof: See appendix 3.

Lemma 5.2 shows that the principal wants to induce positive problem-solving efforts (i.e., $f_i^* > 0$). As a result, each agent's wage increases as the principal evaluates the benefits of the problem-solving activity as more favorable (i.e., $a_r = b_r > 0$). The principal wants to utilize her personal and imperfect evaluation when she evaluates the agents' problem-solving efforts and their effectiveness. The proportion of the rewards based on the principal's evaluation, however, decreases as the principal' judgement error (i.e., σ_r^2) increases. Clearly, as the principal's judgment error increases, the value of subjective evaluation as information about the agents' problem-solving efforts decreases and, hence, the principal decreases the weight of her subjective evaluation in determining the agents' rewards.

A more important result is the effects of these problem-solving activities on incentive contracts with respect to the agents' production tasks. Lemma 5.2 shows that each agent's rewards increase as his performance on his own production task increases. Conversely, the rewards for the other agent's performance depend on several factors in the problem-solving and production tasks. The following proposition summarizes the effects:

Proposition 5.1: *Let* $v^* = \rho\sigma^2(1+r\sigma_y) / \sigma_r^2(1+2r\sigma^2(1-\rho))$. *(i) JPE with respect to the agents production tasks (i.e.,* $a_2^* > 0$ *and* $b_1^* > 0$*) is optimal if* $v^2 > v^*$. *(ii) JPE is always optimal if* $\rho < 0$. *(iii) If* $\rho > 0$, $\partial v^*/\partial\rho > 0$ *and* $\partial v^*/\partial\sigma_r < 0$.

Proof: See appendix 3.

Proposition 5.1 shows that the form of the optimal incentive contract with respect to the agents' production tasks depends on the effects of the problem-solving activities on production tasks and the accuracy of the principal's subjective evaluation of the agents' problem-solving efforts. Specifically, proposition 5.1 shows that JPE is optimal if the effects of agent i's problem-solving effort on agent j's performance (v) is bigger than a critical value (v^*). Although there exists a performance measure with respect to the problem-solving task (x_r), the principal chooses to use JPE to induce optimal problem-solving effort if the effects of the agent i's problem-solving effort on agent j's performance is significant. If the effects of agent i's problem-solving effort on agent j's performance is significant, both agents do not exercise optimal problem-solving effort under RPE since their problem-solving efforts increase the performance of the other agent, which may reduce the agents' rewards. Therefore, if there are significant effects of problem-solving effort, the principal utilizes JPE to induce the agents' problem-solving efforts.

The second result in proposition 5.1 shows that JPE is always optimal if $\rho < 0$. This is because an agent's good performance signals the possibility of favorable environmental shocks, which in turn implies the possibility of unfavorable environmental shocks to the other agent. Since the agents are compensated more if unfavorable environmental shocks are realized, an agent's rewards increase as the other agent's performance increases. This result holds even if there is no uncertainty associated with problem-solving efforts (i.e., $\sigma_r = 0$).

In contrast, the principal can use RPE to elicit information about the common environmental shock if $\rho > 0$. In this case, it is important to compare this benefit of RPE to the benefits of JPE in inducing problem-solving effort. The third result in proposition 5.1 shows the area within which RPE is optimal increases as the effects of the common environmental shocks on the agents' production tasks, ρ, increase given $\rho > 0$. In this case, the benefit associated with information about the common environmental shocks increases and, therefore, the value of RPE increases. The third result of the proposition 5.1, however, also shows that the critical value (v^*) increases as σ_r increases if $\rho > 0$. Therefore, the area within which JPE is optimal increases as the uncertainty associated with the principal's evaluation increases. As the uncertainty associated with the principal's evaluation increases, the informational value of her evaluation about the agents' problem-solving efforts decreases and the importance of the agents' production performance as an additional information source about the agents' problem-solving efforts increases. In this case, JPE can maximize information about an agent's problem-solving effort since both agents' performance is affected by the agent's problem-solving effort, although the principal loses information about the common environmental shocks which can be elicited if she uses RPE.

5.4 Conclusion

In this chapter, I examine situations where (i) an agent's effort affects both his and the other agent's performance in sequential production and (ii) both agents are engaged in problem-solving activities. The analysis of the first situation shows that the form of an agent's incentive contract depends on the effect of the agent's effort on the performance measure. If the first agent can affect the outcome of the second task while the second agent cannot affect the outcome of the first task, the first agent's optimal incentive contract is JPE since the principal can better off by using information about both agents' performance and compensating the first agent positively with respect to both agents' performance. Conversely, the second agent's optimal incentive contract resembles RPE since the principal wants to discern the effects of the outcome of the first task on the final outcome from the second agent's compensation. Although the optimal contract resembles RPE, the source of this type of incentive contract is not the common environmental shocks usually examined in the literature, but the fact that the second agent's performance includes both agents' contributions.

The analysis of the second situation shows that a team-oriented incentive contract (i.e., JPE) with respect to production tasks can be used to motivate an agent to exercise desired problem-solving efforts when they are assigned to both problem-solving tasks and production tasks and the errors associated with the principal's subjective evaluation on the problem-solving efforts are sufficiently large. Furthermore, it is shown that the area within which JPE is optimal increases as the uncertainty associated with the principal's evaluation increases. As the uncertainty increases, the benefits of team-oriented performance measurement (i.e., JPE) increase since JPE maximizes information about an agent's problem-solving effort by allowing the principal to examine the effects of an agent's problem-solving efforts on both agents' performance. Although Itoh (1991, 1992) shows a similar result introducing the possibility of an agent's helping effort, his model does not consider the possibilities of the principal's evaluation of problem-solving efforts and an agent's problem-solving effort improving both agent's performance simultaneously.

Chapter 6. Concluding Remarks

This dissertation analyzes the design of managerial accounting systems in the context of performance evaluation and control. In particular, the focus of this dissertation is the optimality of team-oriented organizational structures and performance measurement systems. Although the economic benefits of competition-oriented organizational structures are relatively well examined in the literature, the economic benefits of team-oriented organizational structures and cooperation-oriented performance measurement systems have seldom been examined until recently. This dissertation provides a theoretical rationale for the effective use of team-oriented performance measurement systems through the analysis of the implications of specific relationships among agents and their tasks for the design of performance measurement systems. These results help to understand the sources of benefits associated with team-oriented organizational structures and performance measurement systems. Furthermore, clarification of the relationships between performance measurement systems and other organizational characteristics can lead to improved managerial accounting systems, which in turn lead to improved organization members' decision making and organizations' overall performance.

Using several principal-multiagent models, I derive conditions under which team-oriented performance measurement systems are optimal. First, I examine conditions under which information systems based on team performance measures are better than information systems based on individual performance measures for motivating an agent. The analysis in chapter 3 shows that team-oriented information systems are optimal if: (i) the realization of the externality of the other agent's performance increases as the agent's effort increases, or (ii) the realization of the externality decreases as the agent's effort increases and the effects of the agent's effort on his performance decreases as the other agent's performance increases. In both cases, the agent utilizes information about the other agent's performance measures to decide his effort level. This decision-facilitating effect of individual information increases the principal's expected costs of inducing the agent's desired effort, and hence leads to team-oriented performance measurement systems. Furthermore, as the accuracy of individual performance measures increases, the negative effects of individual information systems increase. Therefore, the benefits of information generated by a performance measurement system should be examined in terms of employees' task structures and employees' uses of information since more accurate information is not always beneficial for organizations.

Second, the analysis in chapter 4 demonstrates that (i) the relationship between the cooperation activities and the individual productive activities and (ii) the significance of the effects of the cooperation activities on the individual productive activities determine the effectiveness of team-oriented performance measurement systems. Although the principal loses information about agents' environmental factors by using team-oriented performance measurement systems, team-oriented systems enable the principal to induce the agents' cooperation activities more effectively if the cooperative activities and the productive activities are significantly separable. Hence, the analysis shows that the optimality of team-oriented performance measurement systems depends not on the existence of the employees' cooperation opportunities, but on the relationship between employees' cooperation opportunities and individual productive activities.

Finally, in chapter 5, I examine the effects of agents' problem-solving activities on performance measurement systems. It is assumed the employer can subjectively assess the effectiveness of the outcomes of the problem-solving task on production tasks. The analysis shows that team-oriented performance measurement systems with respect to production tasks can be used to motivate the agents to exercise proper problem-solving efforts if the errors associated with the principal's subjective assessment of problem-solving activities are significantly large. Therefore, the benefits of team-oriented performance measurement systems stem from their ability to induce employees' cooperation by complementing imperfect performance evaluation of problem-solving activities.

There are several future research areas to examine. First, this dissertation does not examine the detailed implications of various modern manufacturing and management concepts on performance measurement systems and organizational structures. For example, Just-In-Time (JIT), Flexible Manufacturing Systems (FMS), and lean production change the manufacturing processes and the relationships among agents. As a result, understanding interactions between those changes and performance measurement systems and organizational structures becomes important in business success. Therefore, future research should include a rich set of manufacturing and management practices and examine the efficiency and effectiveness of team-oriented approaches.

Second, the effectiveness of "teams" is determined not only by performance measurement systems but also by various organizational features such as interactions among team members and their tasks, interrelationships among various teams, management styles and structures, organizational environment, and education/training (e.g., Hackman, 1990; Dumain, 1994; Miller and Butler, 1996). Although this dissertation addresses some of these features, many important features remain to be examined. For example, the answers to the following questions will provide some insights about the benefits of team-based organizational structures: (i) Who should be included in a team? What attributes of team members produce an effective team? (ii) To what extent is it beneficial to allow teams to decide their performance goals and activities? (iii) What are the optimal relationships among various teams? Is it optimal to allow teams to compete against each other?

Finally, empirical tests of the results can be performed. The effects of information systems, task structures, agents' relationships, and performance measurement systems on team members' decision makings can be examined through field studies, experiments, or archival tests. Furthermore, empirical research may identify more subtle interactions among team members.

Appendix 1: Proofs (Chapter 3)

Proof of lemma 3.1:

Some additional notation is defined to simplify the analysis:

$k_1 = prob(x_G : e_h, e_H) = p_h q_{H,g} + (1-p_h) q_{H,b}$;

$k_2 = prob(x_B : e_h, e_H) = p_h(1-q_{H,g}) + (1-p_h)(1-q_{H,b})$;

$k_3 = prob(x_G : e_\ell, e_H) = p_\ell q_{H,g} + (1-p_\ell) q_{H,b}$;

$k_4 = prob(x_B : e_\ell, e_H) = p_\ell(1-q_{H,g}) + (1-p_\ell)(1-q_{H,b})$;

$k_5 = prob(x_G : e_h, e_L) = p_h q_{L,g} + (1-p_h) q_{L,b}$;

$k_6 = prob(x_B : e_h, e_L) = p_h(1-q_{L,g}) + (1-p_h)(1-q_{L,b})$;

$k_7 = prob(x_G : e_\ell, e_L) = p_\ell q_{L,g} + (1-p_\ell) q_{L,b}$;

$k_8 = prob(x_B : e_\ell, e_L) = p_\ell(1-q_{L,g}) + (1-p_\ell)(1-q_{L,b})$.

Using these probabilities, the principal's problem under the team information system can be rewritten as the following:

$$\min_{s1,\, s2} \quad EC_p = k_1(s_1(x_G)+s_2(x_G)) + k_2(s_1(x_B)+s_2(x_B))$$

$$k_1 s_1(x_G) + k_2 s_1(x_B) - c_1(e_h) \geq 0 \qquad \text{(P1)}$$

$$k_1 s_2(x_G) + k_2 s_2(x_B) - c_2(e_H) \geq 0 \qquad \text{(P2)}$$

$$k_1 s_1(x_G) + k_2 s_1(x_B) - c_1(e_h) \geq k_3 s_1(x_G) + k_4 s_1(x_B) - c_1(e_\ell) \qquad \text{(I1)}$$

$$k_1 s_2(x_G) + k_2 s_2(x_B) - c_2(e_H) \geq k_5 s_2(x_G) + k_6 s_2(x_B) - c_2(e_L) \qquad \text{(I2)}$$

$$s_1(x_G) \geq c_1(e_h) \qquad \text{(L1)}$$

$$s_1(x_B) \geq c_1(e_h) \qquad \text{(L2)}$$

$s_2(x_G) \geq c_2(e_H)$ (L3)

$s_2(x_B) \geq c_2(e_H)$ (L4)

The first two constraints (P1) and (P2) are two agents' individual rationality constraints, and the second two constraints (I1) and (I2) are their incentive compatibility constraints. The last four constraints represent the two agent's limited liability constraints. Since the individual rationality constraints are trivially satisfied due to the limited liability constraints, the proof focuses only on the incentive compatibility constraints. Equation (I1) can be rewritten as

$$(k_1 - k_3)s_1(x_G) + (k_2 - k_4)s_1(x_B) \geq \Delta_1,$$

or

$$(k_1 - k_3)(s_1(x_G) - s_1(x_B)) \geq \Delta_1. \qquad \text{(I1')}$$

Since an increase in $s_1(x_B)$ requires an accompanying increase in $s_1(x_G)$, the optimal $s_1(x_B)$ is the minimum payment, which is $c_1(e_h)$. Since equation (I1') is binding, the optimal $s_1(x_G)$ is

$$s_1(x_B) + \Delta_1 / (k_1 - k_3).$$

Similarly, equation (I2) reveals that the optimal incentive contract should be

$$s_2(x_B) = c_2(x_H), \text{ and } s_2(x_G) = s_2(x_B) + \Delta_2 / (k_1 - k_5).$$

□

Proof of lemma 3.2:

Some additional notation is defined to simplify the analysis:

$$m_1 = prob(x_G : I_g, e_h, e_H) = \alpha_h q_{H,g} + (1-\alpha_h)q_{H,b};$$

$m_2 = prob(x_B : I_g, e_h, e_H) = \alpha_h(1-q_{H,g}) + (1-\alpha_h)(1-q_{H,b});$

$m_3 = prob(x_G : I_g, e_h, e_L) = \alpha_h q_{L,g} + (1-\alpha_h)q_{L,b};$

$m_4 = prob(x_B : I_g, e_h, e_L) = \alpha_h(1-q_{L,g}) + (1-\alpha_h)(1-q_{L,b});$

$m_5 = prob(x_G : I_b, e_h, e_H) = prob(x_G : I_b, e_\ell, e_H) = q_{H,b};$

$m_6 = prob(x_B : I_b, e_h, e_H) = prob(x_B : I_b, e_\ell, e_H) = (1-q_{H,b});$

$m_7 = prob(x_G : I_b, e_h, e_L) = prob(x_G : I_b, e_\ell, e_L) = q_{L,b};$

$m_8 = prob(x_B : I_b, e_h, e_L) = prob(x_B : I_b, e_\ell, e_L) = (1-q_{L,b});$

$m_9 = prob(I_g : e_h) = p_h + (1-\beta)(1-p_h);$

$m_{10} = prob(I_b : e_h) = \beta(1-p_h);$

$m_{11} = prob(I_g : e_\ell) = p_\ell + (1-\beta)(1-p_\ell);$

$m_{12} = prob(I_b : e_\ell) = \beta(1-p_\ell);$

$m_{13} = prob(x_G : I_g, e_\ell, e_H) = \alpha_\ell q_{H,g} + (1-\alpha_\ell)q_{H,b};$

$m_{14} = prob(x_B : I_g, e_\ell, e_H) = \alpha_\ell(1-q_{H,g}) + (1-\alpha_\ell)(1-q_{H,b});$

$m_{15} = prob(x_G : I_g, e_\ell, e_L) = \alpha_\ell q_{L,g} + (1-\alpha_\ell)q_{L,b};$

$m_{16} = prob(x_B : I_g, e_\ell, e_L) = \alpha_\ell(1-q_{L,g}) + (1-\alpha_\ell)(1-q_{L,b}).$

Using these probabilities, the principal's problem under the individual information system can be written as the following:

$$\min_{s1,s2} \quad EC_p = \{m_9[m_1 s_1(I_g,x_G)+m_2 s_1(I_g,x_B)] + m_{10}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)]\}$$
$$+ \{m_9[m_1 s_2(I_g,x_G)+m_2 s_2(I_g,x_B)] + m_{10}[m_5 s_2(I_b,x_G)+m_6 s_2(I_b,x_B)]\}$$

subject to

$$m_9[m_1 s_1(I_g,x_G)+m_2 s_1(I_g,x_B)] + m_{10}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)] - c_1(e_h) \geq 0 \quad \text{(P3)}$$

$$m_1 s_2(I_g,x_G) + m_2 s_2(I_g,x_B) - c_2(e_H) \geq 0 \quad \text{(P4)}$$

$$m_5 s_2(I_b,x_G) + m_6 s_2(I_b,x_B) - c_2(e_H) \geq 0 \quad \text{(P5)}$$

$$m_9[m_1 s_1(I_g,x_G)+m_2 s_1(I_g,x_B)] + m_{10}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)] - c_1(e_h)$$
$$\geq m_{11}[m_{13} s_1(I_g,x_G)+m_{14} s_1(I_g,x_B)] + m_{12}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)] - c_1(e_\ell) \quad \text{(I3)}$$

$$m_1 s_2(I_g,x_G) + m_2 s_2(I_g,x_B) - c_2(e_H) \geq m_3 s_2(I_g,x_G) + m_4 s_2(I_g,x_B) - c_2(e_L) \quad \text{(I4)}$$

$$m_5 s_2(I_b,x_G) + m_6 s_2(I_b,x_B) - c_2(e_H) \geq m_7 s_2(I_b,x_G) + m_8 s_2(I_b,x_B) - c_2(e_L) \quad \text{(I5)}$$

$$s_1(I_g,x_G) \geq c_1(e_h) \quad \text{(L5)}$$

$$s_1(I_g,x_B) \geq c_1(e_h) \quad \text{(L6)}$$

$$s_1(I_b,x_G) \geq c_1(e_h) \quad \text{(L7)}$$

$$s_1(I_b,x_B) \geq c_1(e_h) \quad \text{(L8)}$$

$$s_2(I_g, x_G) \geq c_2(e_H) \quad \text{(L9)}$$

$$s_2(I_g, x_B) \geq c_2(e_H) \quad \text{(L10)}$$

$$s_2(I_b, x_G) \geq c_2(e_H) \quad \text{(L11)}$$

$$s_2(I_b, x_B) \geq c_2(e_H) \quad \text{(L12)}$$

Since the individual rationality constraints are trivially satisfied due to the limited liability constraints, the proof focuses only on the incentive compatibility constraints. Equation (I3) can be rewritten as

$$(m_9 m_1 - m_{11} m_{13}) s_1(I_g,x_G) + (m_9 m_2 - m_{11} m_{14})\, s_1(I_g,x_B)$$
$$- (m_{12} - m_{10})[m_5 s_1(I_b,x_G) + m_6 s_1(I_b,x_B)] \geq \Delta_1. \quad \text{(I3')}$$

Since $(m_{12} - m_{10}) > 0$ and any increases in either $s_1(I_b,x_G)$ or $s_1(I_b,x_B)$ must be accompanied by the increases in $s_1(I_g,x_G)$ and/or $s_1(I_g,x_B)$, the principal limits $s_1(I_b,x_G)$ and $s_1(I_b,x_B)$ to the minimum wage, which is $c_1(e_h)$. Then, equation (I3′) can be rewritten as

$$(m_9m_1 - {}_{11}m_{13})s_1(I_g,x_G) + (m_9m_2 - m_{11}m_{14})\, s_1(I_g,x_B) - (m_{12} - m_{10})c_2(e_H) \geq \Delta_1. \qquad \text{(I3″)}$$

Since equation (I3″) is binding, the following relationship can be obtained:

$$\partial s_1(I_g,x_G) \,/\, \partial s_1(I_g,x_B) = -(m_9m_2 - m_{11}m_{14}) \,/\, (m_9m_1 - m_{11}m_{13}). \qquad \text{(I3‴)}$$

Then, it can be shown that the principal's expected costs (EC_p) increases as $s_1(I_g,x_B)$ increases:

$$\begin{aligned} \partial EC_p \,/\, \partial s_1(I_g,x_B) &= m_9m_1\,[\partial s_1(I_g,x_G) \,/\, \partial s_1(I_g,x_B)] + m_9m_2 \\ &= -m_9m_1\,[(m_9m_2 - m_{11}m_{14}) \,/\, (m_9m_1 - m_{11}m_{13})] + m_9m_2 \\ &= (1 - \beta)v_H \,/\, (q_{H,g} - (1-\beta)q_{H,b}) \\ &\geq 0. \end{aligned}$$

Therefore, the principal limits $s_1(I_g,x_B)$ to the minimum wage. The optimal level of $s_1(I_g,x_G)$ can be obtained from equation (I3″):

$$(m_9m_1 - m_{11}m_{13})s_1(I_g,x_G) + (m_9m_2 - m_{11}m_{14})\, c_1(e_h) - (m_{12} - m_{10})c_1(e_h) \geq \Delta_1,$$

or

$$(m_9m_1 - m_{11}m_{13})(s_1(I_g,x_G) - c_1(e_h)) + (m_9 - m_{11})\, c_1(e_h) - (m_{12} - m_{10})c_1(e_h) \geq \Delta_1,$$

or

$$s_1(I_g,x_G) = \Delta_1 \,/\, (m_9m_1 - m_{11}m_{13}) + c_1(e_h),$$

or

$$s_1(I_g,x_G) = \Delta_1 \,/\, ((p_h - p_l)(q_{H,g} - (1-\beta)q_{H,b})) + c_1(e_h).$$

To derive the second agent's incentive contract, equations (I4) and (I5) can be rewritten as

$$(m_1 - m_3)\,(s_2(I_g,x_G) - s_2(I_g,x_B)) \geq \Delta_2; \qquad (I4')$$

$$(m_5 - m_7)\,(s_2(I_b,x_G) - s_2(I_b,x_B)) \geq \Delta_2. \qquad (I5')$$

Following the previous logic, it is evident that the incentive contract specified in lemma 3.2 is optimal under the individual information system.

□

Proof of observation 3.1:

(1) Suppose $\beta \in [0, 1)$. Then, $\alpha_h > p_h$. If $\theta_g > \theta_b$, then $B_2^g < B_2^T < B_2^b$ since $\alpha_h > p_h$ and $(\alpha_h \theta_g + (1-\alpha_h)\,\theta_b) > (p_h\,\theta_g + (1-p_h)\,\theta_b) \geq \theta_b$. Similarly, if $\theta_g < \theta_b$, then $B_2^g > B_2^T > B_2^b$. If $\theta_g = \theta_b$, then $B_2^g = B_2^T = B_2^b$.

(2) Suppose $\beta = 1$. Then, $B_2^g = B_2^T$ since $a_h = p_h$. The comparison between B_2^T and B_2^b can be obtained by using the same analysis in (1).

□

Proof of proposition 3.1:

From equation (3.6), it is clear that $W_2^T - W_2^I < 0$ if (1) $(\theta_g - \theta_b) > 0$ and $(v_H - v_L) > 0$ or (2) $(\theta_g - \theta_b) < 0$ and $(v_H - v_L) < 0$. Therefore, it suffices to prove the following:

(1) $(\theta_g - \theta_b) > 0$ if $(v_H - v_L) > 0$,

and

(2) $(v_H - v_L) < 0$ if $(\theta_g - \theta_b) < 0$.

First, suppose $(v_H - v_L) > 0$. Then,

$$
\begin{aligned}
(\theta_g - \theta_b) &= (q_{H,g} - q_{L,g}) - (q_{H,b} - q_{L,b}) \\
&= (q_{H,g} - q_{H,b}) - (q_{L,g} - q_{L,b}) \\
&= q_{H,b}(v_H - 1) - q_{L,b}(v_L - 1) \\
&\geq q_{H,b}(v_H - v_L) \\
&> 0.
\end{aligned}
$$

Second, suppose $(\theta_g - \theta_b) < 0$. Then,

$$
\begin{aligned}
(v_H - v_L) &= (v_H - 1) - (v_L - 1) \\
&= q_{H,b}^{-1}(q_{H,g} - q_{H,b}) - q_{L,b}^{-1}(q_{L,g} - q_{L,b}) \\
&\leq q_{H,b}^{-1}[(q_{H,g} - q_{H,b}) - (q_{L,g} - q_{L,b})] \\
&= q_{H,b}^{-1}[(q_{H,g} - q_{L,g}) - (q_{H,b} - q_{L,b})] \\
&= q_{H,b}^{-1}(\theta_g - \theta_b) \\
&< 0.
\end{aligned}
$$

□

<u>Proof of proposition 3.2</u>:

The principal's problem under the delayed individual information system can be written as the following:

$$
\begin{aligned}
\underset{s1,\, s2}{\text{Min}} \quad EC_p = &\{m_9[m_1 s_1(I_g,x_G)+m_2 s_1(I_g,x_B)] + m_{10}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)]\} \\
&+ \{m_9[m_1 s_2(I_g,x_G)+m_2 s_2(I_g,x_B)] + m_{10}[m_5 s_2(I_b,x_G)+m_6 s_2(I_b,x_B)]\}
\end{aligned}
$$

subject to

$$
m_9[m_1 s_1(I_g,x_G)+m_2 s_1(I_g,x_B)] + m_{10}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)] - c_1(e_b) \geq 0
$$

$$m_9[m_1 s_2(I_g,x_G) + m_2 s_2(I_g,x_B)] + m_{10}[m_5 s_2(I_b,x_G) + m_6 s_2(I_b,x_B)] - c_2(e_H) \geq 0$$

$$m_9[m_1 s_1(I_g,x_G)+m_2 s_1(I_g,x_B)] + m_{10}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)] - c_1(e_h)$$

$$\geq m_{11}[m_{13} s_1(I_g,x_G)+m_{14} s_1(I_g,x_B)] + m_{12}[m_5 s_1(I_b,x_G)+m_6 s_1(I_b,x_B)] - c_1(e_l)$$

$$m_9[m_1 s_2(I_g,x_G) + m_2 s_2(I_g,x_B)] + m_{10}[m_5 s_2(I_b,x_G) + m_6 s_2(I_b,x_B)] - c_2(e_H)$$

$$\geq m_{11}[m_3 s_2(I_g,x_G) + m_4 s_2(I_g,x_B)] + m_{12}[m_7 s_2(I_b,x_G) + m_8 s_2(I_b,x_B)] - c_2(e_L)$$

$s_1 \geq c_1(e_h)$ and $s_2 \geq c_1(e_H)$.

The principal's problem under the team information system is the same as the above problem with the following four additional constraints:

$s_1(I_g,x_G) = s_1(I_b,x_G)$;

$s_1(I_g,x_B) = s_1(I_b,x_B)$;

$s_2(I_g,x_G) = s_2(I_b,x_G)$;

$s_2(I_g,x_B) = s_2(I_b,x_B)$.

Since the delayed individual information system can always mimic the team information system, it is at least the same as, and sometimes dominant over, the team information system.

□

Appendix 2: Proofs (Chapter 4)

Proof of lemma 4.1:

Since JPE, BRPE, and TRPE are derived in the text, it suffices to prove that $w_{01} = w_{00} = 0$ under the optimal incentive contract. Moreover, since both agents' individual rationality constraints are not binding, I will focus only on equations (4.2) and (4.3), which can be rewritten as the following:

$$((p_1+\varepsilon)^2 - p_1^2)\, w_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_1(1-p_i))\, w_{10}$$
$$+ ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1)\, w_{01} + ((1-p_1-\varepsilon)^2 - (1-p_1)^2)\, w_{00}$$
$$\geq 0; \qquad (4.2')$$

$$((p_1+\varepsilon)^2 - p_0 p_1)\, w_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))\, w_{10}$$
$$+ ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)p_1)\, w_{01} + ((1-p_1-\varepsilon)^2 - (1-p_0)(1-p_1))\, w_{00}$$
$$\geq e / (1-\sigma). \qquad (4.3')$$

Since $(1-p_1-\varepsilon)^2 - (1-p_0)(1-p_1) < (1-p_1-\varepsilon)^2 - (1-p_1)^2 < 0$, an increase in w_{00} decreases the left-hand sides of equations (4.2′) and (4.3′). Therefore, it is obvious that the principal does not pay agent *i* if both agents' tasks fail (i.e., $w_{00}^* = 0$) because an increase in w_{00} requires an increase in either w_{11}, w_{10}, or w_{01} to satisfy equations (4.2′) and (4.3′), increasing the principal's expected costs.

Furthermore, the principal does not pay agent *i* if agent *i*'s task fails but agent *j*'s task succeeds (i.e., $w_{01}^* = 0$). To see this, first suppose that $((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) < 0$. Since $0 > ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) > ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)p_1)$, equations (4.2′) and (4.3′) imply that an increase in w_{01} requires an increase in either w_{11} or w_{10}. Hence, $w_{01}^* = 0$.

Second, suppose that $((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) > 0$ and $w_{01} > 0$. The cooperation-related incentive condition (4.2′) holds trivially because $((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) > 0$. Now, it can be shown that the principal is strictly better off by decreasing w_{01} down to zero with an appropriate increase in w_{10}. The work-related incentive constraint (4.3′) implies that $\partial w_{10} / \partial w_{01} = -((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)p_1) / (p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1)) > -1$ and, hence, $\partial C/\partial w_{01} = (p_1+\varepsilon)(1-p_1-\varepsilon)((\partial w_{10}/\partial w_{01}) + 1) > 0$. Since the principal's expected costs increase as w_{01} increases, the principal can decrease her expected costs by decreasing w_{01} and increasing w_{10} while ensuring that equation (4.2′) holds. Therefore, $w_{01}^* = 0$.

□

Proof of proposition 4.1:

(i) Suppose that $\varepsilon > \text{Max}\{0, 1-2p_1\}$. Since TRPE is not possible if $\varepsilon > 1-2p_1$, the proof proves that the expected costs for the principal under JPE are less than the expected costs under BRPE if $\sigma < \sigma^*$.

$$C_J - C_{BR} = -e(\varepsilon+2p_1)(\varepsilon p_0(\varepsilon+p_1) - \sigma(\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon)) / ((1-\sigma)(p_1-p_0)(p_1+\varepsilon)(\varepsilon^2+2\varepsilon p_1-p_0p_1+p_1^2)).$$

Hence, $C_J - C_{BR} < 0$ iff

$$\varepsilon p_0(\varepsilon+p_1) - \sigma(\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon) > 0,$$

or

$$\sigma < \sigma^* = \varepsilon p_0(\varepsilon+p_1)/(\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon)).$$

(ii) Suppose $\varepsilon \leq 1\text{-}2p_1$. Then, the proof compares only JPE and TRPE because BRPE is (weakly) dominated by TRPE due to the linearity of the principal's problem if $\varepsilon \leq 1\text{-}2p_1$. A simple calculation shows that $C_J - C_{TR} > 0$ iff

$$\varepsilon p_0(\varepsilon+p_1) - \sigma(\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon) < 0,$$

or

$$\sigma > \sigma^*.$$

□

Proof of proposition 4.2:

(1) $\partial\sigma^* / \partial\varepsilon = (p_0(1-p_1)(\varepsilon^2 + (2\varepsilon+p_1)(p_1-p_0)) / ((1-\varepsilon-p_1)^2(\varepsilon-p_0-\varepsilon p_0+p_1)^2) > 0.$

(2) $\partial\sigma^* / \partial p_0 = (\varepsilon(p_1+\varepsilon)^2) / ((1-\varepsilon-p_1)(\varepsilon-p_0-\varepsilon p_0+p_1)^2) > 0.$

(3) $\partial\sigma^* / \partial p_1 = (\varepsilon p_0(\varepsilon^2 - p_0(1+\varepsilon) + 2\varepsilon p_1 + p_1^2)) / ((1-\varepsilon-p_1)^2(\varepsilon-p_0-\varepsilon p_0+p_1)^2) < 0$ iff

$$\varepsilon < \tfrac{1}{2}(p_0 - 2p_1 + (p_0(4+p_0-4p_1))^{\frac{1}{2}}.$$

□

Proof of lemma 4.2:

Suppose the cooperation and work decisions are separable.

(i) $s_{01} = s_{00} = 0$ *under the optimal incentive contract.*

If the cooperation and work decisions can be separated, the formal principal's problem is

$$\begin{aligned} Min_{[s_{11},s_{10},s_{01},s_{00}]}\ Z = {} & 2[(\sigma+(1-\sigma)(p_1+\varepsilon)(p_1+\varepsilon))s_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)s_{10} \\ & + (1-\sigma)(1-p_1-\varepsilon)(p_1+\varepsilon)s_{01} + (1-\sigma)(1-p_1-\varepsilon)(1-p_1-\varepsilon)s_{00}] \end{aligned}$$

subject to

$$(\sigma+(1-\sigma)(p_1+\varepsilon)(p_1+\varepsilon))s_{11} + (1-\sigma)(p_1+\varepsilon)(1-p_1-\varepsilon)s_{10}$$

$$+ (1-\sigma)(1-p_1-\varepsilon)(p_1+\varepsilon)s_{01} + (1-\sigma)(1-p_1-\varepsilon)(1-p_1-\varepsilon)s_{00} \geq 0; \qquad \text{(IR)}$$

$$((p_1+\varepsilon)^2 - p_1^2)\, s_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_1(1-p_1))\, s_{10}$$

$$+ ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1)\, s_{01} + ((1-p_1-\varepsilon)^2 - (1-p_1)^2)\, s_{00} \geq 0; \qquad \text{(IC1)}$$

$$((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))\, s_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1-\lambda\varepsilon))\, s_{10}$$

$$+ ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)(p_1+\lambda\varepsilon))\, s_{01} + ((1-p_1-\varepsilon)^2 - (1-p_0)(1-p_1-\lambda\varepsilon))\, s_{00}$$

$$\geq e/(1-\sigma). \qquad \text{(IC2)}$$

$$((p_1+\varepsilon)^2 - p_0p_1)\, s_{11} + ((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))\, s_{10}$$

$$+ ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)p_1)\, s_{01} + ((1-p_1-\varepsilon)^2 - (1-p_0)(1-p_1))\, s_{00} \geq e/(1-\sigma). \qquad \text{(IC3)}$$

$$s_{x_i x_j} \geq 0,\ i = 1, 2,\ j = 1, 2,\ i \neq j,\ x_i \in \{0, 1\}, \text{ and } x_j \in \{0, 1\}. \qquad \text{(LL)}$$

Equation (IR) denotes agent 1 and agent 2's individual rationality constraints. There are three incentive compatibility constraints for each agent. Equation (IC1) represents agent 1 and agent 2's cooperation-related incentive compatibility constraints given both agents "work". Equation (IC2) represents agent 1 and agent 2's work-related incentive compatibility constraints given both agents are "cooperative". Equation (IC3) represents agent 1 and agent 2's incentive compatibility constraints to simultaneously induce both cooperation and work. Finally, equation (LL) represents both agents' limited liability constraint. Since the left-hand side of equation (IR) is always non-negative due to the limited liability constraints, both agents' individual rationality constraints are not binding.

Since $(1-p_1-\varepsilon)^2-(1-p_0)(1-p_1) < (1-p_1-\varepsilon)^2-(1-p_1)^2 < 0$ and $(1-p_1-\varepsilon)^2-(1-p_0)(1-p_1-\lambda\varepsilon) < 0$, an increase in s_{00} decreases the left-hand sides of conditions (IC1), (IC2), and (IC3). Therefore, it is obvious that the principal does not pay agent *i* if both agents' tasks fail (i.e., $s_{00}^* = 0$) because an increase in s_{00} requires an increase in either s_{11}, s_{10}, or s_{01} to satisfy equations (IC1), (IC2) and (IC3), increasing the principal's expected costs.

Furthermore, the principal does not pay agent *i* if agent *i*'s task fails but agent *j*'s task succeeds (i.e., $s_{01}^* = 0$). To prove this, first suppose that $((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) < 0$. Since $0 > ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) > ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)p_1) > ((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)(p_1+\lambda\varepsilon))$, equations (IC1), (IC2), and (IC3) imply that an increase in s_{01} must accompany with an increase in either s_{11} or s_{10}. Hence, $s_{01}^* = 0$. Second, suppose that $((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) > 0$ and $s_{01} > 0$. Equation (IC1) holds trivially because $((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_1)p_1) > 0$. Furthermore, equations (IC2) or (IC3) or both are binding under the optimal contract. Now, it can be shown that the principal is strictly better off by decreasing s_{01} down to zero with an appropriate increase in s_{10}. Equation (IC2) implies that $\partial s_{10} / \partial s_{01} = -((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)(p_1+\lambda\varepsilon)) / (p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1-\lambda\varepsilon)) > -1$. Equation (IC3) implies that $\partial s_{10} / \partial s_{01} = -((1-p_1-\varepsilon)(p_1+\varepsilon) - (1-p_0)p_1) / (p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1)) > -1$. Therefore, under the optimal contract, $\partial Z/\partial s_{01} = (p_1+\varepsilon)(1-p_1-\varepsilon)((\partial s_{10}/\partial s_{01}) + 1) > 0$. Since the principal's expected costs increase as s_{01} increases, the principal can decrease her expected costs by decreasing s_{01} and increasing s_{10} while requiring the binding incentive constraint(s) to hold. Therefore, $s_{01}^* = 0$.

(ii) *The optimal incentive contract is one of JPE, IPE, BRPE, or TRPE.*

The optimal contract for agent *i* in the separable case must be one of the following three wage schemes:

(S1) $s_{11} > 0$, and $s_{10} = 0$;

(S2) $s_{11} = 0$, and $s_{10} > 0$;

(S3) $s_{11} > 0$, and $s_{10} > 0$.

The schemes (S1) and (S2) represent JPE and TRPE, respectively. If the contract form (S1) is optimal, then the binding incentive constraint (4.14) implies

$$s_{11} = e / [(1-\sigma)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))] \text{ and } s_{10} = 0,$$

which trivially satisfies the two other incentive constraints since

$$0 < (p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon) < (p_1+\varepsilon)^2 - p_0p_1 < (p_1+\varepsilon)^2 - p_1^2.$$

The expected costs for the principal under this JPE contract are

$$Z_J = (\sigma + (1-\sigma)(p_1+\varepsilon)^2)e/[(1-\sigma)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))].$$

If the contract form (S2) is the optimal incentive contract, then $\varepsilon \leq 1-2p_1$ to satisfy the cooperation-related incentive constraint (4.13). If $\varepsilon \leq 1-2p_1$, the binding incentive constraint (4.15) implies

$$s_{11} = 0 \text{ and } s_{10} = e / [(1-\sigma)((p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1))],$$

which is TRPE. TRPE satisfies the two other incentive constraints only if $\varepsilon \leq 1-2p_1$ since

$$0 < (p_1+\varepsilon)^2 - p_1(1-p_1) \text{ only if } \varepsilon < 1-2p_1,$$

and

$$(p_1+\varepsilon)^2 - p_1(1-p_1) < (p_1+\varepsilon)^2 - p_0(1-p_1) < ((p_1+\varepsilon)^2 - p_0(1-p_1-\lambda\varepsilon)).$$

The expected costs for the principal under this TRPE contract are

$$Z_{TR} = (p_1+\varepsilon)(1-p_1-\varepsilon))e \,/\, [(p_1+\varepsilon)(1-p_1-\varepsilon) - p_0(1-p_1)].$$

If the contract form (S3) is optimal, then two of the three incentive compatibility constraints are binding.[67] First, if equations (4.13) and (4.14) bind, then

$$s_{11} = (\varepsilon - (1-2p_1))e \,/\, (p_1(\varepsilon-p_0+p_1)(1-\sigma)) \text{ and } s_{10} = (\varepsilon+2p_1)e \,/\, (p_1(\varepsilon+p_1-p_0)(1-\sigma)).$$

This incentive contract, however, violates the limited liability constraints since $s_{11} < 0$. Furthermore, it cannot satisfy equation (4.15) because the left-hand side of equation (4.15) using the suggested s_{11} and s_{10} results in $-(\varepsilon p_0)e \,/\, (p_1(\varepsilon-p_0+p_1)(1-\sigma))$, which is negative. This implies that inducing "work" and "cooperation" separably cannot induce "work" and "cooperation" simultaneously. If the principal induces "work" ("cooperation") alone assuming "cooperation" ("work") as a given, the agents choose to "shirk" and effect "noncooperation".

Second, if equations (4.14) and (4.15) bind,

$$s_{11} = s_{10} = e \,/\, ((\varepsilon+p_1-p_0)(1-\sigma)) = s,$$

which satisfies equation (4.13) since the left-hand side of equation (4.13) is εs, which is trivially non-negative. If the principal constructs the incentive scheme under which "work and cooperation" weakly dominates both "shirk and cooperation" and "shirk and noncooperation", then she can assure that "work and cooperation" (weakly) dominates "work and noncooperation". Moreover, the incentive scheme shows the principal pays the

---

[67] If only one incentive compatibility constraint is binding, the linearity of the problem implies either s_{11} or s_{10} must be zero. All three constraints are binding only if $\varepsilon = 0$.

agent if the agent's task succeeds regardless of the other agent's performance. Also, the principal's expected costs under the IPE scheme are

$$Z_{IPE} = (\sigma + (1-\sigma)(p_1+\varepsilon))e \,/\, ((\varepsilon+p_1-p_0)(1-\sigma)).$$

Finally, equations (4.13) and (4.15) bind only if $\varepsilon > 1-2p_1$. Otherwise, equation (4.13) is trivially satisfied for any s_{11} and s_{10} combination, which implies either JPE or TRPE is optimal. If equations (4.13) and (4.15) bind, the suggested wage scheme is

$$s_{11} = (\varepsilon - (1-2p_1))e \,/\, ((p_1-p_0)(p_1+\varepsilon)(1-\sigma))$$

and

$$s_{10} = (2p_1+\varepsilon)e \,/\, ((p_1-p_0)(p_1+\varepsilon)(1-\sigma)),$$

which satisfies equation (4.14). This scheme is exactly BRPE because $s_{11} < s_{10}$. The principal's expected costs under BRPE are

$$Z_{BR} = (\sigma(\varepsilon - (1-2p_1)) + (1-\sigma)p_1(p_1+\varepsilon))e \,/\, (1-\sigma)(p_1-p_0)(p_1+\varepsilon).$$

□

<u>**Proof of proposition 4.3**</u>:

A comparison between Z_{IPE} and Z_J shows that

$$Z_J - Z_{IPE} = (\lambda-\lambda^*)e \,/\, [(1-\sigma)(p_1+\varepsilon-p_0)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))],$$

where

$$\lambda^* = [\varepsilon p_0(p_1+\varepsilon) - \sigma(1-p_1-\varepsilon)(p_1+\varepsilon-p_0-\varepsilon p_0)] \,/\, [\varepsilon p_0(\sigma + (1-\sigma)(p_1+\varepsilon))].$$

Therefore, $Z_J > Z_{IPE}$ if and only if $\lambda > \lambda^*$.

□

Proof of corollary 4.1:

It can be rewritten that $\lambda^* = (A-\sigma B) / (C+\sigma D)$, where A, B, C, and D are constants. The corollary can be easily proved by differentiating λ^* by σ.

□

Proof of proposition 4.4:

The following two lemmas are established to prove proposition 4.4.

***Lemma 4.3**: IPE dominates JPE if $\sigma \geq \sigma^\lambda$, where*

$$\sigma^\lambda = (1-\lambda)\varepsilon p_0(p_1+\varepsilon) / [(1-p_1-\varepsilon)(p_1+\varepsilon+\lambda\varepsilon p_0-p_0-\varepsilon p_0)] < \sigma^*.$$

JPE dominates IPE if $\sigma < \sigma^\lambda$.

Proof: A comparison between Z_{IPE} and Z_J shows that

$$Z_J - Z_{IPE} = (\sigma-\sigma^\lambda)e / [(1-\sigma)(p_1+\varepsilon-p_0)((p_1+\varepsilon)^2 - p_0(p_1+\lambda\varepsilon))],$$

which is non-negative if $\sigma \geq \sigma^\lambda$.

□

***Lemma 4.4:** If $\sigma < \sigma^*$, IPE dominates both TRPE and BRPE. If $\sigma \geq \sigma^*$, BRPE dominates TRPE and IPE for $\varepsilon \in (Max\{0, 1-2p_1\}, 1-p_1)$ and TRPE dominates BRPE and IPE for $\varepsilon \in (0, Max\{0, 1-2p_1\}]$.*

Proof: Let Z_{BR} and Z_{TR} denote the principal's expected costs under BRPE and TRPE, respectively. If $\varepsilon > 1-2p_1$, then TRPE is not feasible, and the comparison between Z_{IPE} and Z_{BR} shows

$$Z_{IPE} - Z_{BR} = -e(\varepsilon p_0(\varepsilon+p_1) - \sigma(\varepsilon+p_1-p_0-\varepsilon p_0)(1-p_1-\varepsilon)) / ((1-\sigma)(p_1-p_0)(p_1+\varepsilon)(\varepsilon+p_1-p_0)).$$

Hence, $Z_{IPE} - Z_{BR} < 0$ iff

$$\varepsilon p_0(\varepsilon+p_1) - \sigma(\varepsilon+p_1 - p_0 - \varepsilon p_0)(1-p_1-\varepsilon) > 0,$$

or

$$\sigma < \sigma^* = \varepsilon p_0(\varepsilon+p_1) / ((\varepsilon+p_1 - p_0 - \varepsilon p_0)(1-p_1-\varepsilon)).$$

Similarly, if $\varepsilon < 1-2p_1$, it can be shown that $Z_{IPE} - Z_{TR} < 0$ iff $\sigma < \sigma^*$.

□

Proof of proposition 4.4:

(1) Suppose $\sigma < \sigma^\lambda$. Then, lemma 4.3 shows that JPE dominates IPE. Also, lemma 4.4 shows IPE dominates BRPE and TRPE since $\sigma^\lambda < \sigma^*$. Therefore, JPE is optimal for all $\varepsilon \in (0, 1-p_1)$ if $\sigma < \sigma^\lambda$.

(2) Suppose $\sigma^\lambda \leq \sigma < \sigma^*$. Then, lemma 4.3 shows that IPE dominates JPE since $\sigma \geq \sigma^\lambda$. Also, lemma 4.4 shows that IPE dominates BRPE and TRPE since $\sigma < \sigma^*$. Therefore, IPE is optimal for all $\varepsilon \in (0, 1-p_1)$ if $\sigma^\lambda \leq \sigma < \sigma^*$.

(3) Suppose $\sigma \geq \sigma^*$. Then, lemma 4.3 shows that IPE dominates JPE since $\sigma^* \geq \sigma^\lambda$. Also, lemma 4.4 shows that IPE is dominated by BRPE for $\varepsilon \in (\text{Max}\{0, 1-2p_1\}, 1-p_1)$ and by TRPE for $\varepsilon \in (0, \text{Max}\{0, 1-2p_1\}]$. Finally, lemma 4.2 shows TRPE is not feasible for $\varepsilon \in (\text{Max}\{0, 1-2p_1\}, 1-p_1)$ and BRPE is dominated by BRPE for $\varepsilon \in (0, \text{Max}\{0, 1-2p_1\}]$. Therefore, BRPE is optimal for $\varepsilon \in (\text{Max}\{0, 1-2p_1\}, 1-p_1)$ and TRPE is optimal for $\varepsilon \in (0, \text{Max}\{0, 1-2p_1\}]$.

□

Appendix 3: Proof (Chapter 5)

Proof of lemma 5.1:

(i) Given the assumptions of the linear compensation and the exponential utility functions, the agents' expected utility can be calculated as

$$EU_1(e_1) = -\exp[-r(a_0+a_1e_1+a_2(e_2+ve_1)-½e_1^2-½r(a_1^2\sigma_1^2+a_2^2\sigma_2^2+2a_1a_2\sigma_{12}))], \quad (A1)$$

and

$$EU_2(e_2) = -\exp[-r(b_0+b_1e_1+b_2(e_2+ve_1)-½e_2^2-½r(b_1^2\sigma_1^2+b_2^2\sigma_2^2+2b_1b_2\sigma_{12}))]. \quad (A1')$$

Let CEV_i be the certainty equivalent value of taking the contract and performing the task with risk. Then, it follows from (A1) and (A1′) that

$$CEV_1 = a_0 + a_1e_1 + a_2(e_2+ve_1) - ½r(a_1^2\sigma_1^2+a_2^2\sigma_2^2+2a_1a_2\sigma_{12}) - ½e_1^2, \quad (A2)$$

and

$$CEV_2 = b_0 + b_1e_1 + b_2(e_2+ve_1) - ½r(b_1^2\sigma_1^2+b_2^2\sigma_2^2+2b_1b_2\sigma_{12}) - ½e_2^2. \quad (A2')$$

which consists of an expected compensation, a risk premium, and a cost of exerting effort. Since maximizing $EU_i(e_i)$ is equivalent to maximizing CEV_i, the agents' incentive compatibility constraints can be obtained from the first order condition of the maximization problem of (A2) and (A2′) as follows:

$$a_1 + va_2 - e_1 = 0, \quad (A3)$$

and

$$b_2 - e_2 = 0. \quad (A3')$$

Also, the agents' individual rationality constraints can be written as follows:

$$a_0 + a_1e_1 + a_2(e_2+ve_1) - ½r(a_1^2\sigma_1^2+a_2^2\sigma_2^2+2a_1a_2\sigma_{12}) - ½e_1^2 \geq 0, \quad (A4)$$

and

$$a_0 + a_1e_1 + a_2(e_2+ve_1) - ½r(a_1{}^2\sigma_1^2+a_2{}^2\sigma_2^2+2a_1a_2\sigma_{12}) - ½e_1{}^2 \geq 0. \qquad (A4')$$

Therefore, the principal's problem can be rewitten as

$$\text{Max } EU_p = e_2 + ve_1 - E(s_1(I_{x1}, x_2)) - E(s_2(I_{x1}, x_2))$$

s.t.

$$a_0 + a_1e_1 + a_2(e_2+ve_1) - ½r(a_1{}^2\sigma_1^2+a_2{}^2\sigma_2^2+2a_1a_2\sigma_{12}) - ½e_1{}^2 \geq 0,$$

$$a_0 + a_1e_1 + a_2(e_2+ve_1) - ½r(a_1{}^2\sigma_1^2+a_2{}^2\sigma_2^2+2a_1a_2\sigma_{12}) - ½e_1{}^2 \geq 0,$$

$$e_1 = a_1 + va_2,$$

$$e_2 = b_2.$$

Using standard Lagrangian techniques, the optimal solution can be specified as in lemma 5.1.

(ii) It is easy to see that $\partial e_1/\partial v > 0$ and $\partial e_2/\partial v = 0$.

(iii) These results follow directly from the fact that $\sigma_{12} = v\hat{\sigma}_0^2$, $\sigma_1{}^2 = \hat{\sigma}_0{}^2 + \hat{\sigma}_1{}^2$, and $\sigma_2{}^2 = v^2\hat{\sigma}_0{}^2 + \hat{\sigma}_2{}^2$.

□

<u>**Proof of lemma 5.2**</u>:

Following the same logic as in the proof of lemma 5.1, the principal's problem can be rewitten as

$\text{Max } E(x_1 + x_2) - E(s_1 + s_2)$

subject to

$a_0 + a_r E(x_r) + a_1 E(x_1) + a_2 E(x_2) - \frac{1}{2}r(a_1^2\sigma^2+a_2^2\sigma^2+a_r^2\sigma_r^2+2a_1a_2\sigma_{12}) = \frac{1}{2}(f_1^2+e_1^2)$,

$b_0 + b_r E(x_r) + b_1 E(x_1) + b_2 E(x_2) - \frac{1}{2}r(b_1^2\sigma^2+b_2^2\sigma^2+b_r^2\sigma_r^2+2b_1b_2\sigma_{12}) = \frac{1}{2}(f_2^2+e_1^2)$,

$e_1 = a_1$,

$e_2 = b_2$,

$f_1 = a_r + v\,(a_1 + a_2)$,

$f_2 = b_f + v\,(b_1 + b_2)$.

Using standard Lagrangian techniques, the optimal solution can be identified as in lemma 5.2.

□

Proof of proposition 5.1:

(i) $a_2^* > 0$ iff

$$v^2\sigma_r^2(1+2r\sigma^2-2r\rho\sigma^2) - \rho\sigma^2(1+r\sigma_r^2) > 0$$

or

$$v > v^*,$$

where $v^* = \rho\sigma^2(1+r\sigma_r) / (\sigma_r^2(1+2r\sigma^2(1-\rho)))$.

(ii) If $\rho < 0$, $v > 0 > v^*$.

(iii) $\partial v^* / \partial\sigma_r = -\rho\sigma^2 /(\sigma_r^4(1+2r\sigma^2(1-\rho))) < 0$ if $\rho > 0$. Finally, it can be easily seen that $\partial v^*/\partial\rho > 0$ if $\rho > 0$.

□

References

Abramis, D. J. 1990. Semiconductor manufacturing team. In *Groups That Work (and Those That Don't),* edited by J. R. Hackman. San Francisco: Josse-Bass Publishers.

Alchian, A. A., and H. Demsetz. 1972. Production, information costs, and economic organization. *American Economic Review* 62: 777-795.

Arya, A., J. Fellingham, and J. Glover. 1997. Teams, repeated tasks, and implicit incentives. Journal of Accounting and Economics 23: 7-30.

Babson, S. 1995. Lean production and labor: empowerment and exploitation. In *Lean Work: Empowerment and Exploitation in the Global Auto Industry*. edited by S. Babson. Detroit: Wayne State University Press.

Baiman, S. 1990. Agency Research in Managerial Accounting; A Second Look. *Accounting, Organizations and Society 14*: 341-371.

Baiman, S., and J. Demski. 1980. Economically Optimal Performance Evaluation and Control Systems. *Journal of Accounting Research* 18: 184-220.

Baiman, S., J. H. May, and A. Mukherji. 1990. Optimal Employment Contracts and the Returns to Monitoring in a Principal-Agent Context. *Contemporary Accounting Research 6*: 761-799.

Baiman, S., M. V. Rajan. 1994. On the Design of Unconditional Monitoring Systems in Agencies. *The Accounting Review 69*: 217-229.

Che, Y. K., and S. W. Yoo. 1997. Optimal incentive contracts for teams. Working Paper. The University of Wisconsin-Madison.

Cheney, A. B., H. P. Sims, Jr., and C. C. Manz. 1993. Teams and total quality management: an international application. In *Business Without Bosses*, edited by Charles C. Manz and Henry P. Sims, Jr.: John Wiley and Sons, Inc.

Choi, Y. K. 1993. Managerial incentive contracts with a production externality. *Economic Letters* 42: 37-42.

Christensen, J. 1981. Communication in agencies. *Bell Journal of Economics*: 661-674.

----------. 1982. The determination of performance standards and participation. *Journal of Accounting Research* 20: 589-603.

Cohen, S. G., Corporate restructuring team. In *Groups that Work (and Those That Don't)*, edited by J. R. Hackman. San Francisco: Josse-Bass Publishers.

Cremer, J. 1995. Arm's length relationships. *The Quarterly Journal of Economics* CX: 265-295.

Demski, J. S., and G. A. Feltham. 1976. *Cost Determination: A Conceptual Approach.* Ames: Iowa State University Press.

Demski, J. S., and D. Sappington. 1984. Optimal incentive contracts with multiple agents. *Journal of Economic Theory* 33: 152-171.

---------, and ---------. 1989. Hierarchical structure and responsibility accounting. *Journal of Accounting Research* 27: 40-58.

Dumaine, B. 1994. The trouble with teams. *FORTUNE* (September): 86-92.

Dye, R. A. 1986. Optimal Monitoring Policies in Agencies. *Rand Journal of Economics 17*: 339-350.

Eccles, R. G., and D. B. Crane. 1988. *Doing Deals: Investment Banks at Work.* Boston: Harvard Business School Press.

Feltham, D. A., and J. Xie. 1994. Performance measure congruity and diversity in multi-task principal/agent relations. *The Accounting Review* 69: 429-453.

Grant, R. M., R. Shani, and R. Krishnan. 1994. TQM's challenge to management theory and practice. *Sloan Management Review* (Winter): 25-35.

Green, J. R., and N. L. Stokey. 1983. A comparison of tournaments and contracts. *Journal of Political Economy* 91: 349-364.

Grossman, S. J. and Hart O.D. 1983. An analysis of the principal agent problem. *Econometrica* 51: 7-46.

Hackman, J. R. 1990. Work teams in organizations: an orienting framework. In *Groups That Work (and Those That Don't)*, edited by J. R. Hackman. San Francisco: Josse-Bass Publishers.

Hemmer, T. 1995. On the interrelation between production technology, job design, and incentive. *Journal of Accounting and Economics* 19: 209-245.

Hiromoto, T. 1991. Restoring the relevance of management accounting. *Journal of Management Accounting Research* 3: 1-15.

Hoerr, J. 1989. The payoff from teamwork. *Business Week* (July): 56-62.

Holmstrom, B. 1979. Moral hazard and observability. *Bell Journal of Economics* 10: 74-91.

---------. 1982. Moral hazard in teams. *Bell Journal of Economics* 13: 324-340.

---------, and P. Milgrom. 1987. Aggregation and linearity in the provision of intertemporal incentives. *Econometrica* 55: 303-328.

---------, and ---------. 1990. Regulating trade among agents. *Journal of Institutional and Theoretical Economics* 146: 85-105.

---------, and ---------. 1991. Multitask principal-agent analyses: incentive contracts, asset ownership, and job design. *Journal of Law, Economics, & Organization* 7: 524-552.

---------, and J. Tirole. 1991. Transfer pricing and organization form. *Journal of Law, Economics, and Organization* 7: 201-228.

Itoh, H. 1991. Incentives to help in multi-agent situation. *Econometrica* 59: 611-636.

---------. 1992. Cooperation in hierarchical organizations: an incentive perspective. *Journal of Law, Economics, & Organization* 8: 321-345.

---------. 1993. Coalitions, Incentives, and Risk Sharing. *Journal of economic Theory* 60: 410-427.

Ittner C. D., and D. F. Larcker. 1994. Total quality management and the choice of information and reward systems. Working Paper, University of Pennsylvania.

Johnson, H. T. 1992. *Relevance Regained: From Top-Down Control to Bottom-Up Empowerment.* New York: McGraw-Hill.

Jordan, J. S. 1990. Accounting-based divisional performance measurement: incentives for profit maximization. *Contemporary Accounting Research 6*: 903-921.

Katzenbach, J. R., and D. K. Smith. 1993. *The Wisdom of Teams.* Boston, Massachusetts: Harvard Business School Press.

Kim, S. K., And Y. S. Suh. 1992. Conditional Monitoring Policy under Moral Hazard. *Management Science 38*: 1106-1120.

Laffont, J. 1990. Analysis of hidden gaming in a three-level hierarchy. *Journal of Law, Economics, & Organization* 6: 301-324.

Larson, C. E., and F. M. LaFasto. 1989. *Teamwork: What must Go Right/ What must Go Wrong*. Newbury, California: Sage Publications, Inc.

Lazear, E. P. 1989. Pay equality and industrial politics. *Journal of Political Economy* 97: 561-580.

---------, and S. Rosen. 1981. Rank-order tournaments as optimum labor contracts. *Journal of Political Economy* 89: 841-864.

Levine, D. I., and L. D. Tyson. 1990. Participation, productivity, and the firm's environment. In *Paying for Productivity: A Look at the Evidence*, edited by A. S. Blinder. Washington D. C.: The Brookings Institution.

Magee, R. P. 1986. *Advanced Managerial Accounting*. New York: Harper & Row, Publishers.

Manz, C. C., and J. Newstrom. 1990. Self-managing teams in a paper mill: success factors, problems, and lesson learned. *International Human Resource Management Review* 1: 43-60.

---------, and H. P. Sims, Jr. 1993. *Business Without Bosses*. New York: John Wiley and Sons, Inc.

Marschak, J. and R. Radner. 1972. *Economic Theory of Teams*. New Haven: Yale University Press.

McGrath, J. E., and A. B. Hollingshead. 1994. *Groups Interacting with Technology*. Thousand Oaks, California: Sage Library of Social Research 194.

Meyer, C. 1994. How the right measures help teams excel. *Harvard Business Review* (May-June): 95-103.

Milgrom, P. 1988. Employment contracts, influence activities, and efficient organization design. *Journal of Political Economy* 96: 42-60.

---------, and J. Roberts. 1990. The economics of modern manufacturing: Technology, strategy, and organization. *The American Economic Review 80*: 511-528.

---------, and --------. 1994. The firm as an incentive system. *The American Economic Review* 84: 972-991.

---------, and --------. 1995. Complemetarities and fit: Strategy, structure, and organizational change in manufacturing. *Journal of Accounting and Economics 29*: 179-208.

Miller, B. K., and J. B. Butler. 1996. Teams in the workplace. *New Accountant* 12 (November/December): 18-24.

Mohrman, S. A., S. G. Cohen, and A. M. Mohrman Jr. 1995. *Designing Team-Based Organizations*. Jossey-Bass Publishers.

Mookherjee, D. 1984. Optimal incentive schemes with many agents. *Review of Economic Theory* 51: 433-446.

Nalebuff, B. J., and J. E. Stiglitz. 1983. Prizes and incentives: toward a general theory of compensation and competition. *Bell Journal of Economics* 14: 21-43.

Ramakrishnan, R. T. S., and A. V. Thakor. 1991. Cooperation versus competition in agency. *Journal of Law, Economics, & Organization* 7: 248-283.

Sappington, D. 1983. Limited liability contracts between principal and agent. *Journal of Economic Theory* 29: 1-21.

---------. 1991. Incentives in principal-agent relationships. *Journal of Economic Perspective* 5: 45-66.

---------, and J. Demski. 1983. Multi-agent control in perfectly correlated environment. *Economic Letters* 13: 325-330.

Sridhan, S. S., and B. V. Balachandran. 1994. Aggregate performance measures, participation, and organization design. Working Paper, Northwestern University.

Tirole, J. 1986. Hierarchies and bureaucracies: on the role of collusion in organizations. *Journal of Law, Economics, & Organization* 2: 181-214.

---------. 1988. The multicontract organization. *Canadian Journal of Economics* 21: 459-466.

Varian, H. R. 1990. Monitoring agents with other agents. *Journal of Institutional and Theoretical Economics* 146: 153-174.

Williamson, O. E. 1975. *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: The Free Press.

Wetlaufer, S. 1994. The team that wasn't. *Harvard Business Review* (Nov. - Dec.): 22-38.

Young, R. A. 1986. A note on "economically optimal performance evaluation and control systems": the optimality of two-tailed investigations. *Journal of Accounting Research* 24: 231-240.

Young, S. M., J. Fisher, and T. M. Lindquist. 1993. The effects of intergroup competition and intragroup cooperation on slack and output in a manufacturing setting. *The Accounting Review* 68: 466-481.