This is to certify that the

dissertation entitled

The Processing and Aggregation of Information

Within Organizational Structures

presented by

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has been accepted towards fulfillment
of the requirements for

Ph. D. degree in Political Science

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Date 11-17-92

THE PROCESSING AND AGGREGATION OF INFORMATION WITHIN ORGANIZATIONAL STRUCTURES

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Political Science

1992

ABSTRACT

THE PROCESSING AND AGGREGATION OF INFORMATION
WITHIN ORGANIZATIONAL STRUCTURES

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The main theme of this research is to analyze the processing and aggregation of information within organizational structures using a mathematical approach with a formal theoretical method and Bayesian statistical decision theory.

The first research question speaks to the problem of organizational structure: how does organizational structure affect the information transmitted through it? By examining how individuals process information, and an organization aggregates it, this study will show that organizational structure determines the information which managers receive. Different reports might be given to the top manager given a different structure.

The second research question stems directly from the first: what kind of organizational structure will be most appropriate in information processing? When the function of an organization is to predict a certain event from the environment, the top manager would want to spend his time and energy as little as possible in information processing as well as to predict the event as accurately as possible. The key question of structural design involves the question of how to reduce information cost, and how to increase event predictability. By discussing criteria such as information cost and event predictability, and by examining information processing in four basic types of organizational structures, this study will determine which type is most appropriate for information processing.

The third question focuses on the problem of strategic behavior in information processing: what kind of incentive mechanism can be used by the top manager to ensure that subordinates report information honestly in a particular kind of organizational structure? By assuming that field agents are influence maximizers and that there is a feedback process, this study will prove that the relative weight rule will be the Bayesian incentive compatible mechanism. Under this mechanism, the dominant strategy of the field agent is to report honestly; and that of the manager is to use the relative weight rule appropriately. Given the existence of the incentive mechanism, we can compare information cost and event predictability in organizational structures.

Finally it discusses the relation between organizational structure and environment. This study will show that different principles of information processing will be emphasized when facing different characteristics of the environment, and that different structures will work better in different environments.

To my family

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Professor Thomas H. Hammond for his great personality, continuous guidance and encouragement.

I would like to thank Professors Jeffrey Hill, Scott Gates, Kenneth Williams, and Larry Heimann, for serving on my dissertation committee. Also my special thanks go to Professor Brian Humes of the University of Nebraska, Lincoln, Renée Smith of the University of Rochester, Marcus Cheatham, Jonathan Monroe, and Tammy Essig, for reviewing the earlier drafts. The assistance of the Political Science Department staff is greatly appreciated.

Special thanks to the VanAlstine family--Aaron, Jack, and Margie--in Marquette, Michigan, for their deep friendship.

Finally I wish to give special thanks to my wife, Young-Ae, who has prepared luncheon boxes over four years, and my daughter, Iris Jeehyun, who has said "Please don't go to school. Play with me!" with a wonderful kiss every morning.

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1. Introduction

The literature on organizational design has long studied the properties of organizational structures. However, it is still not clear how much structure matters, and what structure should be chosen under what circumstances.

One important aspect of an organizational structure involves its impact on organizational information processing. However, current studies of organizational design have not attempted to analyze information processing directly nor to link organizational structure to information processing. Organizational structure may affect what kind of information the organization gathers, how information is processed and aggregated, how efficient and reliable the organizational information processing will be, and what the organizational decision will be. The purpose of this dissertation is to discover how much organizational structure affects information processing, and what kind of organizational structure will be most appropriate for its organizational environment.

I will address three questions about organizational structure and information processing. The first research question speaks to the problem of organizational structure: how does organizational structure affect the information transmitted through it? Current studies of organizational design argue that organizational structure exerts a strong influence on information flows in organizations, but these studies do not show precisely how organizational structure influences information flows. By examining how individuals process information, and how an organization aggregates it, this study will show that organizational structure determines both the scope of information and the set of information aggregation rules. Organizational structures are about aggregation procedures that transform the individual reports into a collective one. Hence to design an organizational structure is to choose a certain kind of aggregation procedure. Different reports might be given to the top manager given a different structure.

The second research question stems directly from the first: what kind of organizational structure will be most appropriate in information processing? Current studies argue that different organizational structures are appropriate in different situations. However, they do not demonstrate how different structures produce differences in information processing nor do they show how to evaluate information processing in different organizational structures. They have only formulated abstract hypotheses. When the function of an organization is to predict a certain event from the environment, the top manager would want to predict the event as accurately as possible but also to spend as little of his time and energy as possible in information processing. The key question of structural design involves the question of how to reduce information cost, and how to increase event predictability. By discussing criteria such as information cost and event predictability, and by examining information processing in four basic types of organizational structures, this study will determine which type is most appropriate for information processing.

The third question focuses on the problem of strategic behavior in information processing: what kind of incentive mechanism can be used by the top manager to ensure that subordinates report information honestly in a particular kind of organizational structure? If it is useful to deal with the effect of organizational structure on information

processing, it is equally important to consider the role of strategic behavior in information processing. Thus both the organizational structure and the incentive mechanism used to ensure sincere information processing should be linked in the attempt to develop effective organizational responses to the environment. Even a properly structured organization does not ensure sincere information transmission. If the field agent is an expected utility maximizer, he would use a successful strategy and avoid an unsuccessful one. If a strategy is not successful, he will search for alternatives. By assuming that field agents are influence maximizers and that there is a feedback process, this study will prove that the relative weight rule will be a Bayesian incentive compatible mechanism. Under this mechanism, the dominant strategy of the field agents is to report honestly. This mechanism will insure honest reporting given the organizational structure.

This study will focus on how structure affects information processing in the organization. Other upward flows such as policy alternatives or conflict resolution remain to be considered.[1] For the purpose of showing clearly the effects of structure on information flow, *all other factors* influencing information processing except structure are assumed to be constant. However, after discussing and comparing organizational structures, the assumption will be modified. This study will analyze information processing in four models of organizational structures using a mathemathical approach with a formal theoretical approach and Bayesian statistical decision theory. A

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1 Sah and Stiglitz (1985) studies the aggregation of individual errors under different organizational structures. Calvert (1985) argues that the rational decision maker prefers a biased information over a neutral one. Hammond (1986) researches the aggregation of policy options and the resolution of conflicts under different organizational structures.

formalization of organizational structure is useful since it shows why an organizational structure matters, and it is general enough that it can be made more specific with addition of several different variations.

The concept of information processing provides a useful method to explain the characteristics of organizational structures. In this study, an organization is viewed as an information processing system (Marschak and Radner 1972, Galbraith 1969, 1977, Tushman and Nadler 1978, Egelhoff 1982). Information processing refers to the gathering, the transmission, and the aggregation of information in organizational decision making procedures. It is a vital aspect of organizational decision making since organizational decisions depend on information that is imperfect in a number of obvious ways (Feldman and March 1981). Organizations process information for effective management of both "uncertainty," referring to "the difference between the amount of information required and the amount of information possessed by the organization," and "equivocality," that is "the existence of multiple and conflicting interpretations about an organizational situation" (Daft and Lengel 1986, p.556).

Organizational structure exerts a strong influence on information flows in organizations (Aguilar 1967, Galbraith 1977, Egelhoff 1982). Organizational structure and internal processing systems determine the scope of information provided to decision makers (Daft and Lengel 1986). An organization is "(1) composed of people and groups of people (2) in order to achieve some shared purpose (3) through a division of labor (4) integrated by information-based decision processes (5) continuously through time" (Galbraith 1977, p.3).

Following this definition of organization, this study is based on several assumptions about organizations. A basic assumption is that an organization is an open social system which is affected by, and dependent upon, its environment (Lawrence and Lorsch 1967, Thompson 1967, Pfeffer and Salancik 1978). Since there are several sources of uncertainty to which the organization should respond, it should be able to cope with environmental uncertainty. As Otley (1988, p.87) put it: "Both organizational structure and the mechanisms used to establish internal control are linked in the attempt to develop effective organizational responses to environmental conditions."

The second assumption is that an organization is an information processing system. The organization's structure functions to process and aggregate information through hierarchical routes (Galbraith 1969, 1977, Tushman and Nadler 1978, Knight and McDaniel 1979, Kmetz 1984). To anticipate environmental uncertainty, an organization observes the external environment, gathers data, and transmits information. "Information processing comprises (1) the assembly of raw data and information, i.e., the collection of inputs, and (2) modification of the inputs, which include transformation, analysis, or synthesis, into different forms" (Kmetz 1984, p.276). Organizational decision making relies on the information transmitted through the organizational structure.

The third assumption is that an organization is a composition of individuals and divisions based on the principle of the division of labor (Gulick 1937, Mintzberg 1979). Following the principle of "grouping" which is "a fundamental means to coordinate work in the organization" (Mintzberg 1979, p.106), an organization tries to group together subordinates between which information aggregations are important. Each individual or

subunit utilizes a specific method and technology to observe the environment and gather information which differs from the others. Relying on these general assumptions, this study views an organization as an information processing system. In the following section the procedures how to analyze information processing in organizational structures will be introduced.

This study will be organized as follows. The next chapter will review current studies on organizations. This literature review will confirm how important is this research, and show that organizational structure itself has not been thoroughly investigated.

Chapter 3 will describe a hypothetical setting of this research and the problems of information processing. The goal of an organization in this study is to predict the probability of a particular recurring event. The field agents gather information from the external information source (the environment) and transmit the reports on the probability of the occurrence of the event in the near future to the manager. The top manager, who represents the organization, gathers the information and makes the organizational prediction of the event. The individual in the organization is assumed to be a Bayesian player: he/she uses the Bayesian rule in making the report, and follows the principle of expected utility maximization. Secondly, this study will discuss information aggregation and feedback. The organizational structure is about information aggregation. The role of managers is to aggregate the reports from the subordinates and to simplify the information. The relative weight rule will be developed as an appropriate aggregation rule. Thirdly, information cost and event predictability will be discussed as the principles of information processing. The information cost of an organization is the sum of the managers' information processing costs and the field agents' observation costs. But much more important will be the costs of information overload on higher-level managers. Event predictability refers to how accurate is the organizational prediction of the event. For event predictability, the more information an organization generates, the more accurately the organization predicts the event, and the more agreements about the probability an organization produces, the more reliable and objective is that probability. The design of a certain organizational structure means how to give emphasis to these principles. Finally it will attack the third research question by demonstrating that the problem of misrepresentation can be solved by applying the relative weight rule as an incentive mechanism. Under the assumptions that all individuals are Bayesian players and that there exist feedback processes, the relative weight rule is a Bayesian incentive compatible mechanism. In an information processing game the dominant strategy of the field agent is to report honestly and that of the manager is to use the relative weight rule appropriately.

Based on two dimensions important in organizational design (specialization and coordination), Chapter 4 will generate four basic models of organizational structures: Flat one-to-one structure, Deep one-to-one structure, Flat one-to-many structure, and Deep one-to-many structure. It will discuss the characteristics of, and the advantages and disadvantages of, each kind of organizational structure. Different organizational structures transmit different information to the top manager. The information cost of tall structures is less than that of flat structures for the top manager as well as the whole organization.

The flat one-to-one structure generates greater information predictability than the other structural alternatives, given the existence of the relative weight rule. When considering both information cost and information predictability, the tall one-to-one structure is better than the other structures when the number of subordinates is not too small.

Chapter 5 will illustrate the models with a numerical example. This example demonstrates how organizational structures affect the processing and aggregation of information in the organization.

Chapter 6 will analyze the relation between organizational structure and environment. When categorizing the environment with two dimensions dealing with degree of information homogeneity and degree of information stability, this chapter will show that different principles of information processing will be emphasized when facing different characteristics of the environment, and that different structures will work better in different environments.

The concluding chapter will summarize the results of the study, discuss the issues of coalition and risk preference and suggest some directions for further research.

2. Literature Review

Contingency theory, the studies of structure and strategy, transaction cost theory, and principal-agent theory are the bodies of literature most relevant to this research. Contingency theory emphasizes a fit between organizational environment and organizational structure. The studies of structure and strategy focus on the causal relationship between strategy and structure. Transaction cost theory tries to compare different governance structures, mainly focusing on market structure and hierarchical structure. Principal-agent theory asks how to design an incentive system which secures sincere behavior in organizations.

Contingency theorists argue that the structure of an organization should match or fit together internal and external organizational variables (Thompson 1967, Lawrence and Lorsch 1967). The central arguments of contingency theory can be expressed in two equivalent ways:

> 1. [An organization]'s efficiency is dependent on the relation between the state of the environment and the form of the organization; or
>
> 2. Under conditions of efficiency, organizational form is correlated with the state of environment (Grandori 1987, p.1).

Burns and Stalker (1961) suggested that the mechanistic form -- formal and bureaucratic -- is effective in a stable environment, while the organic form -- less formal and more flexible -- is effective in a rapidly changing environment. Different organizational principles are thus appropriate in different organizational environments (Woodward 1965). If a firm is to be successful, its design should be contingent upon the

characteristics of the environment in which it operates. Lawrence and Lorsch (1967) and Lorsch and Allen (1973) observed that the achievement of a degree of differentiation consistent with the requirements of the environment and the achievement of a degree of integration consistent with the required interdependence of these parts was related to higher organizational performance. "The best way to organize depends on the nature of the environment to which the organization must relate" (Scott 1981, p.114).

Earlier findings on the relation between organizational environment and structure were conflicting. Several researchers observed that an increase in environmental uncertainty was associated with a decentralized organizational structure (Lawrence and Lorsch 1967, Duncan 1973). On the other hand, other studies found that an increase in organizational uncertainty was associated with a centralized organizational structure (Huber *et al.* 1975, Bourgeois *et al.* 1978). In addition, some studies showed that there was no evidence for the proposition that organic or decentralized organizations perform better than centralized organizations in uncertain environments (Mohr 1971, Pennings 1975). Recent empirical studies have also shown mixed results.[1]

Contingency theory is criticized for several flaws. Lawrence (1981) summarized the major problems:

1. It is only static, not dynamic.

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[1] Koberg and Ungson (1987) observed that fit between environment and organizational structure does not explain performance. Dastmalchian and Boag (1990) studied the relationships between marketing department structure and organizations' dependencies on markets and customers. The result showed that both specialization and the degree of integration of the marketing department were positively affected by market dependency. Centralization of decision making was positively affected by customer dependency. The results were more evident in successful firms. Departmental formalization was also positively affected by market dependency in successful firms. Randolph et. al. (1991) analyzed the effects of the fit between technological innovation and organizational structure on small businesses. They found that fit has a significant positive relationship with financial performance for low growth companies, but it is unrelated to performance in high growth companies.

2. It did not treat the concept of environmental uncertainty with conceptual clarity.
3. It started a trend that has gone too far in seeking a never-ending stream of contingent variables to account for organizational features.
4. It did not offer an explanation for the observed uniformities (Lawrence 1981).

However, more important is that contingency theory does not explain the core: why and how different organizational structures are appropriate in different organizational environments. Since it does not analyze the characteristics or roles of organizational structure itself, it fails to relate the description of structure with that of organizational functions. Nevertheless, it indicates that organizational structures need to be compared with regard to the characteristics of organizational environment.

The studies on organizational structure and strategy have debated two contradictory arguments: structure follows strategy (Chandler 1962, 1977, Rumelt 1974), and strategy follows structure (Bower 1970, Hedberg *et al.* 1976, Bobbitt and Ford 1980). The doctrine that structure follows strategy was initiated by Chandler (1962), who demonstrated a clear historical connection between the firm's internal structure and the scope of its activities. He argued that structural choice follows from strategic choice. Superior performance is argued to be the product of an appropriate fit between strategy and structure. He found that the most fundamental change in large American corporations was a move from centralized, functionally departmentalized structures (the U Form) to multi-divisional ones (the M Form). Galbraith and Nathanson (1978, 1979) concluded that the organization must achieve a fit between its strategy, its structure, and its processes. But the concept of "fit" is still unclear: "Although the concept of fit is a useful one, it lacks the precise definition needed to test it and to recognize whether an organization has it or not" (Galbraith and Nathanson 1979, p.266).

On the other hand, Bower (1970) argued against the doctrine that structure follows strategy; instead, the organizational structure affects the kind of information which the top manager will receive from subordinates: "When management chooses a particular organization form, it is providing not only a framework for current operations but also the channels along with which strategic information will flow..." (Bower 1970, p.287). Pettigrew (1973) explained strategic action as the result of an internal political process which is affected by the division of labor. Fredrickson (1986) reviewed the strategy/structure debate and concluded that the organizational structure has important deterministic effects on the strategic decision process and its outcome. Hammond (1986) explained how organizational structures might act in ways similar to legislative agendas and thereby affect policy outcomes. Hammond (1991b) concluded that strategy follows structure since the organizational structure affects what information the top manager receives, and what alternatives are made available to him. Bourgeois and Astley (1979) suggested that the relationship between strategy and structure must be reciprocal. Depending upon what part of the strategic process is observed, both "structure follows strategy" and "strategy follows structure" can be correct propositions (Burgelman 1983). Recently, Chandler (1991) has said that structure has as much impact on strategy as strategy has on structure. Boschken (1990) divided structure into two variables, micro-structure and macro-structure. Micro-structure means "a set of coordinated subunits assigned the critical tasks of designing for the whole organization and creating appropriate implementation policies and changes in operational structure," while macro-structure contains all organizational activities (Boschken 1990, p.136). His case study showed that the micro-structure provides a means to determine strategy, while strategy determines the design of a macro-structure. The earlier studies showed that there is no strong proof that a fit between strategy and structure leads to effective performance (Galbraith and Nathanson 1978). Results from recent empirical studies remain inconclusive.[2]

These studies provoke the basic question of this research: why does a organizational structure matter? These studies indicate that an organizational structure has its own effects on organizational functions, whether strategy formulation or strategy implementation or both. But still these studies do not explain what are the characteristics of different organizational structures nor do they prove how different structures affect differently.

Transaction cost theory views the organization as a "stable pattern of transactions" (Ouchi 1980, p.140). "A transaction occurs when a good or service is transferred across a technologically separable interface" (Williamson 1985, p.1). Transaction costs mean "the negotiating, monitoring, and enforcement costs that have to be borne to allow an exchange between two parties to take place" (Jones and Hill 1988, p.160). Transaction costs can be divided into the two types: *ex ante* and *ex post* costs (Williamson 1985). The first are the costs of drafting, negotiating, and safeguarding an agreement. The second include the setup and operating costs of the governance structure. Both the *ex*

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2 Bart (1986) observed that the relationship between strategy and structure is severely constrained. In the study of small and medium sized organizations, Miller (1987) found that the way a business is organized affects its strategic planning and strategy-making procedures. Provan (1989) examined the influence of internal organizational power on strategy and concluded that department power has a strong influence on the planning and implementation of strategy in organizations. In a study of the five largest Canadian banks, Murray and Javidan (1987) conclude that it is misleading to look for the exact casual relationship between strategy and structure, because the two are inextricably bound.

ante and *ex post* costs of transaction are interdependent. The sources of these costs are the transaction difficulties that may be present in the exchange process. The factors producing transaction difficulties are: bounded rationality, opportunism, uncertainty and complexity, small numbers, information impactedness, and asset specificity (Williamson 1975, 1985, Jones and Hill 1988). Transaction cost theory argues that "the costs of economic activities are not technologically-determined but dependent on the form of organization under which the activities are conducted" (Yarbrouch and Yarbrouch 1988, p.7). The core methodological properties of transaction cost theory are:

> 1. The transaction is the basic unit of analysis.
> 2. Human agents are subject to bounded rationality and self-interest.
> 3. The critical dimensions for describing transactions are frequency, uncertainty, and transaction-specific investments.
> 4. Economizing on transaction costs is the principal factor that explains viable modes of contracting; it is the main issue with which organizational design ought to be concerned.
> 5. Assessing transaction cost differences is a comparative institutional exercise (Williamson and Ouchi 1981, p.367).

Coase (1937) used the concept of transaction costs to explain the emergence of the firms. Coase argued that firms only emerge when an exchange in the market place may be more costly than the same exchange in a hierarchical organization. The firm can reduce the transaction costs by lessening information costs, lowering the number of necessary contracts, and lengthening the terms of some contracts. Alchian and Demsetz (1972) argued that when it is difficult to monitor or meter the individual contributions of each member in a team production, and each member has an incentive to shirk, hierarchy has definite monitoring and enforcement advantages for limiting opportunism. Williamson (1975) argued for market trading and internal organization as competing modes of handling transactions.[3] Under conditions of market failure, hierarchy is more efficient than the market mechanism in executing transactions since the contracting parties have greater control and surveillance over uncertainties associated with a transaction and over the personal opportunism of the parties involved. The multi-divisional structure is a more effective means of allocating capital than the other structures.

Transaction costs are economized by assigning transactions to governance structures in a discriminating way (Williamson 1985). Kleig, Crawford and Alchian (1978) focused on vertical integration of production. They pointed out that whenever asymmetric transaction specific investments exist, dependence exists; whenever dependence exists, there exists the potential for opportunistic exploitation of those who are dependent; and, some remedies to the problems associated with dependence are implicit contracts and vertical integration. Ouchi (1980) suggested that the clan form of governance of transactions has some efficiency and advantages. A clan can be seen as an alternative mode of organizing, in addition to markets and hierarchies. A clan can be seen as a set of control mechanisms that are legitimated by "a high degree of goal congruence, typically through relatively complete socialization brought about through high inclusion" (Ouchi 1980, p.136).

Jones (1983) analyzed how organizational culture emerges from the institutional arrangements developed to regulate the transactions between members of an organization. Transaction cost minimization determines the efficient property rights structure that

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3 Williamson (1975, 1985) and Chandler (1962, 1977) argued that hierarchies replaced markets because they were more efficient. However, Williamson focuses on transaction costs, while Chandler on administrative coordination.

defines the organizational culture. Jones (1983) argued: "the form of culture that emerges in an organization may be seen as a consequence of the way in which the firm attempts to economize on the transaction costs associated with its production function. The origin of an organizational culture is the system of property rights that is used to structure the exchange relationships between organization members" (p.465). Recently Williamson (1991) identified three generic forms of economic organization -- market, hybrid, and hierarchy -- and explained that three generic forms are distinguished by different coordinating and control mechanisms and by different abilities to adapt to disturbances.

Empirical studies have provided mixed evidence on the major arguments of transaction cost theory. Some studies showed that there is a positive relationship between the multi-divisional innovation and overall economic performance, while others demonstrated negative or non-significant relations (see Cable 1988). Fligstein and Dauber (1989) reviewed empirical studies of structural change in corporations and concluded that the transaction cost perspective is not supported empirically. One interesting study suggested that the economic approach to organizational structure is valid but insufficient, and needs to be combined with the ecological and political approach (Palmer *et al.* 1987).

The criticisms of transaction cost theory are mainly focused on two questions: what are transaction costs?; and how do hierarchical employment relations reduce these costs? Robins (1987) stated that: "while transaction-cost analysis offers considerable potential as a prescriptive approach to the problems of business strategy, it has far less promise as a means of dealing with the larger issues associated with the evolution of organizational form" (p.82). Dow (1987) said that transaction cost analysis will not provide any causal explanation for the origin or persistence of these structures. Demsetz (1988) argued that the transaction cost is only one element of the cost of purchasing from others, and that there are a variety of others. Dow (1987) and Hammond (1991b) indicated the difficulty of comparing transaction costs. Hammond (1991b) explained:

> Transaction cost analysis would lead us to expect that changing a structure will change the set of transactions that occur because the costs of some transactions will now be greater than their benefits, while the costs of other transactions will now be less than their benefits. But since the two structures are now engaging in somewhat different transactions, there is no common basis for comparison; they are simply two different organizations doing different things. On what basis can it then be argued that one structure is more efficient than the other? (p.13).

The usefulness of transaction cost theory is to provide an analytical framework for comparing the relative costs demanded by different organizational structures. But since the precise nature of transaction cost is unclear, and since without common basis it is difficult to compare transaction costs in different structures with different conditions, it is still questionable how one structure can be compared with another.

Principal-agent theory views an organization as "a cascade of principal-agent relationships," each superior acting as a principal in relation to his subordinates, and as an agent in relation to his own superior (Radner 1991, p.218). Principal-agent relationships arise whenever the principal cannot perfectly and costlessly monitor the agent's action and information (Spence and Zeckhauser 1971, Jensen and Mecking 1976, Holmstrom 1979, 1982, Fama and Jensen 1983, Pratt and Zeckhauser 1985, Hart 1990). Principal-agent theory assumes:

> 1. The principal is in a position to design the monitoring and incentive mechanism.
> 2. All the benefits from improvements in performance go to the principal.

Principal-agent theory starts by making general assumptions about the preference structure of the actors, the nature of uncertainty present, and the information distribution between actors (Jensen 1983). This model incorporates two basic features of organizations: asymmetric information and goal conflict among organization members. The principal-agent theory is concerned with how the principal can design an incentive system which motivates his agent to act in the principal's benefit. An equilibrium of the principal-agent model is:

> 1) Given the announced compensation-pair, the agent chooses his action so as to maximize his own expected utility.
> 2) Given the optimizing behavior of the agent described in 1), the principal chooses a compensation-pair that maximizes his own expected utility (Radner 1991, p.237).

Alchian and Demsetz (1972) suggested that monitoring by hierarchical superiors is necessary where team production makes it impossible to prevent shirking. Jensen and Meckling (1976) argued the problem of the principal-agent relationship exists in all organizations and in all cooperative efforts. Jensen (1983) defines an organization as a legal entity that serves as a nexus for a complex set of contracts among disparate members. Thus the behavior of the organization is the equilibrium behavior of a complex contractual system made up of agents with diverse and conflicting objectives.

The principal-agent problems of asymmetric information can be divided into five categories:

> ...consider the problem of an employer (the principal) hiring a worker (the agent).... If the employer knows the worker's ability, but not his effort level, the problem is moral hazard with hidden actions. If neither player initially knows the worker's ability, but after the worker accepts a contract he discovers it, the problem is moral hazard with hidden information. If the worker knows his ability from the start, but the employer does not, the

> problem is adverse selection. If in addition to the worker knowing his ability from the start, he can acquire education observable by the employer before they make a contract, the problem is signalling. If the worker acquires his education in response to the contract offered by the employer, the problem is screening (Rasmusen 1989, p.134).

Holmstrom (1982) enumerated the three desired characteristics of an incentive system: Nash equilibrium, budget balancing, and Pareto efficiency. Holmstrom examined the problem of free-riding and the role of competition in the case of a principal monitoring many agents. He showed that a problem of moral hazard with hidden actions may occur when there is no uncertainty about output. To solve the shirking problem the principal needs to either enforce the penalties or to finance the bonuses.[4] Groves (1973, Groves and Ledyard 1977, Groves and Loeb 1979) examined the entire class of incentive mechanisms in the context of general team decision models, and discovered a class of truth-inducing mechanisms which are immune to misrepresentation. But Miller (1992, p.154) responded that: "There do exist incentive mechanisms that can induce efficient levels of effort (Holmstrom's joint forcing contract) or accurate revelation of information (Groves-Loeb mechanisms), but they all violate budget balancing." Eisenhardt (1989) summarized the contents of principal-agent theory and then concluded that agency theory provides a unique, realistic, and empirically testable perspective on the problems of cooperative effort (see also Moe 1984, Levinthal 1988). However, principal-agent theory tells us about optimal incentive schemes but not directly about organizational structure (Hart 1990).

Principal-agent theory indicates that the problem of the principal-agent relationship

4 Brehm and Gates (1991) reviewed several models of hierarchical supervision and control.

exists in all organizations, and tell us about incentive schemes. But still unclear is how to design an optimal incentive mechanism for solving this principal-agent problem in organizational contexts. Also it does not tell directly about organizational structure. Thus it is necessary to combine the studies on incentive mechanisms with the studies on organizational structure.

This literature review indicates that an organizational structure has its own impacts on organizational functions, and that organizational structures need to be compared with regard to the environmental characteristics, and the relative costs. It also indicates that the problem of strategic behavior in organizational contexts should be solved. However, this literature review shows that organizational structure itself has not yet been thoroughly investigated, and that the basis of comparing organizational structures has not yet been developed. Still unanswered but important are the issues: what are the characteristics of different organizational structures, and how do different structures affect differently; why and how are different organizational structures appropriate in different organizational environments; and how can the organization design an optimal incentive mechanism for ensuring the sincere behavior? These issues will be thoroughly discussed and solved through the following chapters. The problem of incentive mechanism design, and the basis of comparing organizational structures in information processing will be analyzed in Chapter 3. The characteristics of organizational structures will be discussed and compared in Chapters 4 and 5. The relation between organizational structure and environment will be explained in Chapter 6.

3. Dimensions in Organizational Research

3.1 A hypothetical setting

Assume that the goal of an organization is to predict the possibility of a certain recurring event A--for example, military coups, battles, international conflicts, and riots--which has a set of dimensions, $A = (A_1,...,A_n)$. Assume that the environment E has a set of independent sectors E_i, $E = (E_1,...,E_n)$, $(E_i \cap E_j) = \emptyset$, $E_i \cup E_j = E_i + E_j$. The environment is the part of the external information flow to which the organization responds through observation, belief, and action. E can be understood as the information source through which the organization can get information on A. The event A can be predicted by knowing the environment E.

The responsibility of subordinates or field agents is to observe the environment and report the probability of event A in their area. The field agent would gather some number of samples which he would evaluate as to whether event A will occur or not. Each field agent is independent from the others: it is assumed that there is neither horizontal opinion sharing nor peer reviews, and each agent has his own method of analyzing the data. Thus, even though several agents may observe the same sample (i.e., from the same E_i), their conclusions may be different. The field agent's report does not depend on the others' reports nor does he/she know how the others make their observations. The top manager who represents the organization gathers reports from all subordinates, whether directly or indirectly, and formulates an organizational conclusion from these reports. At each time, the organization predicts the probability whether A will occur or not at a certain point of time in the future.

A1. Individuals as Bayesian players

This study assumes that the individuals in an organization maximize expected utility and act as Bayesian players when they acquire information, revise their probabilities, and act upon this new information. A Bayesian decision model of organizational behavior provides a useful framework for structuring information processing. Individual strategies for reporting an estimate of the probability of event *A* are governed by the expected utility of alternative reports, that is, by the utility attached to each outcome weighted by the assessed probability of its occurrence. The individual would transmit the report he believes will maximize his expected utility. From the Bayesian point of view, the individual has both his own subjective probability, which represents his knowledge and beliefs, and his own utility, which represents his tastes and preferences.

Individual behavior is empirically quite consistent with a Bayesian approach. Experimental research shows that individuals and groups within an organization act as Bayesian players (Viscusi and O'Connor 1984, Viscusi 1985, Viscusi and Magat 1987). For example, after analyzing an experiment on job risks with chemical workers, Viscusi (1985, p.384) concludes:

> Overall, individuals do not possess perfect information about the risks they face, but they do have opportunities to revise beliefs based on their experiences. The observed behavior patterns are consistent with the principal predictions of a Bayesian learning process and subsequent adaptive behavior.

The individual can generate a unique probability distribution over the states of event *A*. In Bayesian perspective, any individual has a subjective probability distribution over the possible values of any parameter that he does not know (Savage 1954, Raiffa 1968). Each individual has past experiences and beliefs that can influence probability estimation. Before observing the environment, he already has some prior probability of event *A*. This probability value is a subjective probability in the sense that it derives totally from the individual's personal information about event *A*. According to Savage (1962, p.163), the subjective probability is "a certain kind of numerical measure of the opinions of somebody about something"; see also French (1982). All probabilities are subjective; some are more "objective" than others only in that a larger group of field agents would assign the same values for these probabilities based on their own information sets (Cyert and DeGroot 1987, ch.2).

The theory of subjective probability is concerned with quantifying judgments of likelihood (Fishburn 1986, Kreps 1988). Let us assume that there is a Boolean algebra β of subsets $X_1, X_2, \ldots$ of a universal set S. $\varnothing$ is the empty set and $\varnothing \subseteq X_i \subseteq S$ for every X_i in β. A probability measure on X_i is a real valued function p: $X_i \rightarrow [0, 1]$ satisfying $p(S) = 1$ and $p(X_1 \cup X_2) = p(X_1) + p(X_2)$ if $X_1 \cap X_2 = \varnothing$. Then let us read $X_1 > X_2$ as "X_1 is more likely than X_2". This binary relation > is "a qualitative probability" (Savage 1954). The basic axiom of subjective probability shows that:

$$X_1 \quad > \quad X_2 \quad \text{iff} \quad p(X_1) \quad > \quad p(X_2).$$

This requires that (i) > is asymmetric and transitive, (ii) $S > \varnothing$ (nontriviality), (iii) $X_1 \geq \varnothing$ (nonnegativity), and (iv) if $X_1 \cap X_3 = X_2 \cap X_3 = \varnothing$, $X_1 > X_2$ iff $X_1 \cup X_3 > X_2 \cup X_3$

(additivity).

This subjective information is used in conjunction with any available objective information. After collecting a sample of information from the environment, he will use the data to form a likelihood function of event *A* and then form a posterior probability by multiplying his prior probability with that likelihood. In continuously iterating observations through time, subordinates process information at time *t*, each using his past knowledge on event *A* at time *t* - 1 as his prior probability. At time *t*, he collects some additional data. Then he will transmit the revised report based on his prior probability and the additional data. Each time a sample of data is observed, the prior distribution on event *A* is updated. By means of this updating, the unknown parameter is determined asymptotically as the variance of its distribution decreases with observations.

In the simplest form, Bayes theorem (Raiffa 1968, Kmenta 1986, ch.6-4, Smith 1988, Lindley 1990) involves two factors: a specific value of the parameter of interest, say, θ, and the sample observation, *x*. The theorem states that:

$$P(\theta|x) = \frac{P(\theta)\, P(x|\theta)}{P(x)}$$

For any value of θ, $P(\theta|x)$ represents the updated, posterior probability of that value of θ, and $P(\theta)$ is the prior probability. $P(x|\theta)$ is the probability of observing the sample given θ, which can be readily identified as the likelihood function. This function summarizes the information about θ as provided by the observed evidence in the environment. $P(x)$ represents the probability of observing the given sample by whatever the value of θ is. It is the marginal probability of sample observations obtained by adding probabilities over all values of θ. Therefore, this quantity does not vary with θ;

its role is that of a normalizing constant, which ensures that the probabilities $P(\theta|x)$ of all possible values of θ add up to unity. For this reason, $P(x)$ is frequently ignored. Thus Bayes theorem for data x and parameter θ is:

$P(\theta|x) \propto P(x|\theta)P(\theta)$ or
Posterior distribution $\propto$ prior distribution $\times$ likelihood function,
where $\propto$ means "is proportional to".

To construct a posterior distribution we need to formulate the likelihood function and the prior distribution. If no sample evidence is available, decisions are based solely on the prior information. But otherwise, if the prior information is noninformative or diffuse, the posterior probability is based only on the observed data. The formation of the prior distribution is unique to the Bayesian approach. If the prior distribution depends on a parameter θ, it is convenient to have a standard family of prior distributions that can be used to represent individuals' prior information. If $P(\theta|x)$ and $P(\theta)$ belong to the same class of distributions, they are called "natural conjugates". This concept of natural conjugate distributions is very useful in Bayesian inference. One convenient property of such a family is that if the prior distribution is provided in the form of a formula, and if this formula, combined with the likelihood function, leads to the same functional form, it is called a conjugate family of prior distributions (Winkler 1968, DeGroot 1970, ch.9).

The most commonly used conjugate family of distributions for θ is the family of beta distributions (Cyert & DeGroot 1987, ch.2, Hastings and Peacock 1974, pp.30-33). An organization needs to know whether event A will occur or not, and each individual is assumed to report the possibility of event A based upon his observation of the environment. Event A is a binary variable that has only two states, occurrence (A = 1) or non-occurrence ($A = 0$). The probability of occurrence is denoted as θ, while that of non-occurrence as $(1 - \theta)$. Observing one piece of evidence of the occurrence of event A in the environment is treated as θ^1, and observing evidence of the non-occurrence of event A as $(1 - \theta)^1$. A sequence of random variables $A_1,\ldots,A_n$ are independent and identically distributed. The parameter θ is said to have a beta distribution with hyperparameters α and β ($\alpha > 0$ and $\beta > 0$) if the probability distribution function of θ is:

$$p(\theta) = \frac{\Gamma(\alpha + \beta)\theta^{\alpha - 1}(1 - \theta)^{\beta - 1}}{\Gamma(\alpha)\Gamma(\beta)} = \frac{\theta^{\alpha - 1}(1 - \theta)^{\beta - 1}}{B(\alpha,\beta)} \qquad 0 \leq \theta \leq 1$$

$$0, \qquad \text{otherwise.}$$

where $B(\alpha,\beta)$ is the beta function with parameters α, β, given by $B(\alpha,\beta) = \int_0^1 \mu^{\alpha - 1}(1 - \mu)^{\beta - 1} d\mu$.

A beta distribution's mean, $E(\theta)$, is $\frac{\alpha}{\alpha + \beta}$ and variance is $\frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$.

If the prior distribution $\propto \theta^{\alpha}(1 - \theta)^{\beta}$ and the likelihood $\propto \theta^{\gamma}(1 - \theta)^{\delta}$, then the posterior $\propto \theta^{\alpha+\gamma}(1 - \theta)^{\beta+\delta}$. If $\alpha > \beta$, the prior information favors values of θ greater than .5, and if $\alpha < \beta$, the prior information favors values of θ less than .5 (Hastings & Peacock 1974, p.31, Figure 5.1). Larger values of $(\alpha + \beta)$ imply greater certainty in the expected value of θ.

In this study it is assumed that individuals in an organization are Bayesian players. The individual i has his own prior information on the possibility of event A, $g_i(A)$, and the likelihood function of event A based on his observations (o_i) on the environment E, $l_i(E_i)$. Thus the individual's posterior probability distribution function of event A is:

$$p_i(A) = f[g_i(A), l_i(E_i)].$$

All of the probability distributions--$p_i(A)$, $g_i(A)$ and $l_i(E_i)$)--belong to the same class of beta distribution. For example, imagine a Bayesian player, a_1, wants to estimate the probability of event A. In the past a_1 observed that A occurred 4 of 7 times, and then a_1's prior information, $g_i(A)$, can be written $\beta(4,3)$.[1] He then observes an additional 8 samples, $o_i = 8$, and has the likelihood, $l_i = \beta(5,3)$ which shows A occurred 5 times out of 8. Then by following the simple Bayes rule, the posterior probability, $p_i(A)$, will be [(4+5)/(4+3+3+5)] = [9/15] = .6. But at certain points, for simplicity, it is assumed that each has a common prior probability or a diffuse prior probability on event A. The individual's reporting strategies will be discussed at the section of information processing game.

A2. Individuals as expected utility maximizers

The Bayesian expected utility framework is of value not only for its normative significance in suggesting how individuals should process information but also for its predictive power in information processing.

It is assumed that the individual in an organization is under uncertainty, since each field agent can observe only a portion of the environment, and cannot get the all of the information which is essential for a perfect prediction of event A, and since each manager cannot directly observe any portion of the environment but relies upon only the

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1 $$\beta(x,y) = \frac{\theta^{x-1}(1-\theta)^{y-1}}{B(x,y)}.$$

The mean of $\beta(x,y) = \dfrac{x}{x+y}$

transmitted reports.

Individuals are assumed to follow the principle of maximizing expected utility: that is, in a given decision situation the individual should choose the alternative with maximal expected utility (Gärdenfors and Sahlin 1988).[2] Let us denote the payoff, w_{ij}, as the result of choosing the alternative, r_i when the state of the world turns out to be s_j. Then the assumptions of expected utility maximization are:

1. Values of payoffs: $w_{ij} > w_{kl}$ iff $U(w_{ij}) > U(w_{kl})$.

2. Values of alternatives: $r_i > r_j$ iff $U(w(r_i)) > U(w(r_j))$.

3. Information about states: $P(s_j) \geq 0$, $\sum P(s_j) = 1$.

4. Probability independence: $P(s_j|r_i) = P(s_j)$, for all s_j and all r_i.

Then the expected utility of r_i is $EU(r_i) = \sum P(s_j)U(w_{ij}(r_i))$.

The goal of the individual i is: max EU_i.

5. Sure-thing principle (Savage 1954):

If the person would not prefer **f** to **g**, either knowing that the event *B* obtained, or knowing that the event ~*B* obtained, then he does not prefer **f** to **g**. Moreover (provided he does not regard *B* as virtually impossible) if he would definitely prefer **g** to **f**, knowing that *B* obtained, and, if he would not prefer **f** to **g**, knowing that *B* did not obtain, then he definitely prefers **g** to **f** (pp.21-2).

There exists a probability measure and a utility measure such that for all alternatives r_i and r_j,

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[2] Lindley (1990) argues that in Bayesian perspective every utility is an expected utility:

You build for Yourself a *small world* including some data, excluding others, and within that small world construct a model for Your beliefs. Now such a world is part of a *larger world* and what You say about the small world may appear incoherent when viewed in the larger perspective....Utility in that small world is an expectation over a larger world that contains it (p.50 and p.54, italics in original).

$$r_i > r_j \qquad \text{iff} \qquad EU(r_i) > EU(r_j).$$

For any information processing behavior that satisfies these assumptions, there exists a utility function that assigns values to different outcomes in such a way that the chosen alternative always has the highest expected utility.[3]

The field agent is assumed to maximize his expected utility, which is assumed to be a function of his influence on information aggregation; that is, his utility is determined basically by whether his report is treated as important or not. The field agents want to influence the organizational decision. The goal of the organization is to predict event A, and the responsibility of field agents is to observe the environment and report the probability of the event in their area. For making the organizational prediction, the manager needs to aggregate the reports from the field agents. When aggregating them, the manager may treat some reports more importantly and the others less importantly. A field agent whose report is treated more importantly exerts more influence on the organizational prediction. Since information processing is the only way to influence the organizational decision, each field agent tries to get more weight in information aggregation.

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3 The principle and the assumptions of maximizing expected utility have been criticized from several viewpoints. Allais (1979, 1987) says that the utility of a monetary prize may be affected by the probability of that prize. Allais argues that the probabilities and utilities may not be independent. Kahneman and Tversky (1979) argues that what determines the value of an alternative is its possible changes in wealth, where changes are evaluated in relation to a reference level. Thus the choice of alternatives is determined by both the utility of the outcomes and a reference level. They demonstrate several classes of decision situations in which actual preferences violate the axioms of expected utility theory. Machina (1982, 1983) has developed a theory of expected utility without the sure-thing principle. He discusses several types of violations of the independence axiom which entails the sure-thing principle and presents the generalized expected utility approach with the function $U(x; F)$ where x is a certain prize and F is a cumulative distribution. See Bernard (1984) for general discussions on utility functions, and see Fishburn (1981) for a review of theories of subjective expected utility.

It is assumed that the field agent's utility is a function of his influence on information aggregation: he can maximize his expected utility only by maximizing his relative influence on information aggregation. When assuming that each field agent observes the environment and processes the probability continuously through the time dimension, a field agent's influence on information aggregation is based on his reputation in the organization.[4] The report of a field agent with a good reputation can get more weight because, through the continuous reporting of information to the manager, it has been shown that his reports are valuable and correct. A field agent with a bad reputation would receive little or no weight. It is assumed that the utility of each field agent is a function of a relative weight, w_i, which measures his influence in information aggregation. Field agents maximize expected utility by maximizing the relative weight, w_i, with the appropriate use of report r_i. The utility function (see Bayarri and DeGroot 1988) is assumed to be:

$$U_i = f(w_i) = \log \frac{w_i}{\sum w_j} \quad , \qquad i \neq j,\ w_i + \sum w_j = 1,\ i + \sum j = n.$$

$$EU_i = p[U(w_i(r_i, A = 1))] + (1 - p)[U(w_i(r_i, A = 0))], \qquad A \in \{0, 1\}.$$

$$\max EU_i$$

where r_i is a_i's report and p is a_i's $p_i(A)$ that event A will occur at t + 1.

That is, the field agents care only about maximizing their relative weight, and do *not* care about anything else. The incentive compatibility and principal-agent literature put

4 For a multi-time information processing, a field agent can calculate his expected utility differently when considering discount factors. With the variations of the discount factors, a field agent will be patient or impatient in reaping the weight in the future. Issues on time dimension and discount factors remain to be considered.

emphases on shirking, monetary payments (such as salaries and bonuses), profit distributions and so forth. But this study is *not* working in that particular tradition *but* focusing only on the relative influence on organizational prediction.

The manager is assumed to maximize his expected utility which is a function of information cost and event predictability. Managers have personality types placed on a dimension between the extreme of carefully considering information cost, but not worrying about event predictability, and the extreme of carefully considering event predictability but not thinking about information cost. Information cost for each individual (*ic*) is defined as the cost of analyzing the reports, ***r***, which he receives and making the report, r_m, which he announces. Event predictability (*ep*) refers to how closely the announced expectation on event *A* approaches the true event. Information cost of each manager would vary with organizational structure, which defines the number of levels in the hierarchy and the span of control of managers. The information cost can be estimated by the manager's position in the organization and the number of reports given to that manager. If the information cost would be fixed, the manager's utility is only a function of event predictability.[5]

The goal of the manager *m* is to maximize his expected utility by maximizing event predictability of his report r_m with the given information cost:

$$U_m = f(ic, ep),$$

$$U_m = f(ep), \qquad \text{if } ic \text{ is constant,}$$

[5] Information cost and event predictability will be more thoroughly discussed in the section dealing with the principles in information processing.

$\max EU_m = p[U(ep(r_m, A = 1))] + (1 - p)[U(ep(r_m, A = 0))], \quad A \in \{0, 1\}.$

Since $U_m = f(ep)$, *m* would maximize the expected value of *ep*, E(*ep*).

$\max E(ep) = p[ep(r_m, A = 1)] + (1 - p)[ep(r_m, A = 0)]$

where r_m is *m*'s report and p is $p_m(A)$ on that event *A* will occur at $t + 1$.

3.2 Information aggregation and feedback

The problem of the optimal design of organizational structures is viewed in terms of the aggregation of information in the organization. Organizations differ not only in what kinds of information individuals generate, but also in how the organizations aggregate information. The basic function of aggregation is to simplify the volume of information which flows through the organizational structure and to reduce information processing cost (Keren and Levhari 1989). In information processing, each level of the organization aggregates upward-directed information and disaggregates downward-directed feedbacks. The aggregation problem is the problem of aggregating or combining different estimates from the field agents into a corresponding combined quantity. It is to transform multidimensional input into unidimentional output.

Simpson's paradox demonstrates that different aggregation methods can affect the information that the top manager would use for organizational decisions (Saari 1987, Haunsperger and Saari 1991). Simpson's paradox states that "the conclusion of the aggregated data differs from a common conclusion of the subpopulations" (Haunsperger and Saari 1991, p.252). Let us examine an example of Simpson's paradox:

Assume each individual has a beta probability distribution function and reports $\beta(x,y)$ where x is the number of good results and y is that of bad

results. Thus the mean value of the probability distribution is calculated as [x/(x+y)]. Suppose a certain drug is tested in *Michigan State University*. First, the data are gathered by two subordinates and the aggregated results are transmitted to the manager. The duty of a_1 in the Department of Agriculture is to test the new drug, d_1, and the standard treatment, d_2, and to report which one is better in one village, for example, *Cherry Lane Village*. That of a_2 is to do the same in another village, *Spartan Village*. The manager would gather the reports from a_1 and a_2 and make a decision whether d_1 or d_2 is accepted for public use. a_1 observes that in 9 out of 24 cases d_1 cures the sick, while in 2 out of 6 cases d_2 is successful. Thus a_1 reports that d_1 is better than d_2 based on the probability calculations, $p(d_1) = .375 > .333 = p(d_2)$. a_2 observes that 3 out of 6 cases d_1 is successful, and 11 out of 24 cases d_2 is good. So a_2 reports that d_1 is better than d_2 with $p(d_1) = .500 > .458 = p(d_2)$. The manager receives the same report from both a_1 and a_2 and with no hesitation he pronounces that the Department of Agriculture approves d_1 for public use based on the experimental result.

Second, the manager directly gathers data from both *Cherry Lane Village* and *Spartan Village*. For d_1 among 30 cases only 12 samples show that d_1 is successful, [(9+3)/(24+6)], while for d_2 13 out of 30 demonstrates d_2 is good, [(2+11)/(6+24)]. Thus $p(d_1) = .400 < .433 = p(d_2)$. When aggregated, the data show d_2 is better than d_1. It shows that the way to aggregate information is an important determinant in information processing. (From a talk by D.G. Saari at Washington University on March 1, 1988, and Saari 1987, p.2).

Simpson's paradox shows that different aggregation methods may make different conclusions from the same data. If a design of organizational structure means to choose a certain kind of aggregation procedures, different organizational structures may generate different decisions from the same volume of information as suggested in Simpson's paradox.

The role of managers is to gather the reports from his subordinates and to aggregate them into his own likelihood function. For managers, the question is how to aggregate information. The manager is assumed to formulate his own aggregation rule, d_m, as a Bayesian player. An aggregation rule transforms any set of individual reports on event A into an organizational (or a divisional) report. Formally, an aggregation rule d_m is a correspondence from the n-fold Cartesian product of reports on p(A) into p(A), d_m: $[0, 1]^n \rightarrow [0, 1]$. The basic rule in information aggregation would be the relative weight rule: $d_m = (w_1,...,w_n)$ (Morris 1983, French 1985, Genest and Zidek 1986, Gradstein & Nitzan 1988, Bayarri and DeGroot 1988, DeGroot and Mortera 1991). The aggregation rule depends only on the manager's assessment of the field agent's relative weight. The aggregation rule involves the application of Bayes rule to formally revise the weight after receiving each report and observing the occurrence of event A.

$$0 \leq w_i \leq 1, \quad \sum w_i = 1.$$

When aggregating reports, the manager will assign a relative weight to each report based on his evaluation of each subordinate.[6] The report of each field agent receives a certain prior weight in information aggregation, and the weight is then updated by the observed state of event A -- whether it has occurred or not. I assume that the manager uses the relative weight rule as his aggregation rule because the manager can easily use it in a real world. Since each field agent has a beta probability distribution function on event A, each time the field agent reports r_i as $\beta_i(a, b)$ it shows that the expected value of θ is $[a/(a + b)]$. Only the individual posterior probability distributions can be reported by r_i, whereas the individually observed data sets and prior distributions cannot be communicated. The manager m compares r_i and assigns a relative weight, w_i, to r_i based on his evaluation on a_i. For example, m estimates r_i at time t based on his experience with a_i until t - 1. If m thinks that r_i at time t - 1 was accurate and valuable, then he will be more likely to consider r_i at t to be valuable. If m determines that r_i is more valuable than r_j, $i \neq j$, he will give a relatively heavier weight to r_i as $w_i > w_j$, $i \neq j$; however, $w_i = w_j$ if the

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6 Bayesian studies of combining probability distributions have developed a number of ways to aggregate subjective probability distributions (see French 1985, Genest and Zidek 1986). Let us denote μ as an aggregated information by $\mu = f(r_i, d_m)$ and r_i is a_i's report.

Linear opinion pool: $\mu = \sum w_i r_i$, $0 \leq w_i \leq 1$, $\sum w_i = 1$.

Generalized linear opinion pool: $\mu = \sum w_i r_i$, $-1 \leq w_i \leq 1$, $\sum w_i = 1$.

Logarithmic opinion pool: $\mu = \dfrac{\prod r_i^{wi}}{\int \prod r_i^{wi}\, d\mu}$.

Generalized logarithmic opinion pool: $\mu = \dfrac{g \prod r_i^{wi}}{\int g \prod r_i^{wi}\, d\mu}$, $g = p(\theta)$.

Log-odds opinion pool: $\mu = \sum w_i \log(o_i/o_o)$, $o_i = p_i/(1 - p_i)$, $o_o = m$'s prior.

importance of r_i and r_j is the same. The weight for r_i depends not only on m's assessment of a_i's relative trustworthiness or reputation but on those of the other field agents as well. Therefore, the weight is relative. The weights are variable in the sense that as m learns more about a_i and r_i through time, w_i must be updated (Morris 1983). The manager decides a_i's relative weight based on his prior assignment and the present report with regard to the other reports:

$$w_i = f(w_i^{t-1}, w_{-i}^{t-1}, r_i, r_{-i}),$$

where $r_{-i} = (r_1,...,r_{i-1}, r_{i+1},...,r_n)$ and w_i^{t-1} means the relative weight to a_i at time t-1. The assigned weight to each field agent directly decides his utility. If the manager has no prior information about his subordinates, then he will use an equal weight with $w_i = (1/n)$. With r_i, the aggregated information, μ_m, is a function of the basic aggregation rule d_m:

$$\mu_m = f(r, d_m) = w'r = \sum w_i r_i,$$

where w' is the transpose of the matrix w.

$$r_m = f(g_m(A), \mu_m).$$

The manager's likelihood function is a summary of a set of reports that is a collection of probability functions. The manager constructs his posterior report, r_m, based on his prior information on event A and its likelihood. When the manager's prior is uniform, that is, $g_m(A) \propto$ constant, the manager should adopt the aggregated information as his own report (Morris 1977). However, in aggregating reports, there is a special principle. If all subordinates report the same information, the manager would accept it as the final report no matter what his prior information is, because one of the purposes of aggregation is to save the time and energy of the managers. If there is a consensus

among subordinates, the manager would not invest his own time to make the report. This principle is stronger than the "Management By Exception" rule.[7] The unanimity principle in information processing is:

Unanimity principle: r_m denotes m's final decision on p(A). r_m is the same as k if and only if all subordinates report k, that is,
$r_m = k$, if and only if $\forall\ i,\ r_i = k,\ i = 1,...,n$. (Morris 1983, Clemen and Winkler, 1990)

Feedback is a vital element in information processing systems. Kaufman (1973) defined "administrative feedback" as "all the processes by which the bureau leaders--the whole headquarters--are apprised of subordinate behavior down to the lowest organizational level" (p.1). Feedback from a higher level of a hierarchy can serve two major functions for an organization member.[8] Feedback can provide subordinates with an estimate as to what reported information is correct or valuable, or wrong or not valuable in making organizational decisions. It can provide reinforcement, rewarding a correct report by increasing its weight, and punishing a wrong one by decreasing its weight. Rewards and punishments for subordinates are confined entirely just to information processing issues. Since subordinates care only about maximizing their relative weights, and do not care about anything else, rewards and punishments are completed by changing the relative weight in information aggregation. Both functions can

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[7] If at least k of the n field agents agree on the probability of event A, the manager will accept that probability as his report; if fewer than k field agents agree on that probability, the manager will invest his own information cost to make the report himself. It is assumed that $k > n/2$ (see Hammond and Horn 1985, p.52).

[8] In the field study, Becker and Klimoski (1989) showed that, while holding the other feedback variables constant, feedback from supervisory and organizational sources was related to reported job performance while feedback from peers and self was not. Higher performers received more positive feedback.

influence each subordinates' subjective probability and observational accuracy. Feedback shows whether the manager is consistent in applying the relative weights (Te'eni 1991). Feedback can affect information processing by motivating the managers to choose appropriate weights and by instructing the field agents to choose successful reporting strategies. Through the process of feedback the manager can update his aggregation rule and the field agent can revise his prior probability and strategy.

Table 1: Information Processing and Aggregation

Time & step	**Field agents** a_i	**Manager** m
t, 1	has prior $g_i(A)$	has prior $g_m(A)$
2	observes E	
3	reports r_i	assigns prior weight w_i
4		aggregates $\boldsymbol{r}$
5		reports r_m
$t+1$, 1	event A	event A
2	updates $g_i(A)$	updates $g_m(A)$
3	observes E	revises w_i
4	reports r_i	assigned the updated weight
5		aggregates $\boldsymbol{r}$
6		reports r_m
$t+2$, 1	event A	event A

I assume that observation and information processing is continuous through time dimension with feedback. The process of feedback and updating the weight could be carried out repeatedly as $t \rightarrow \infty$. Since the revised weight is going to be used at the next time, it is natural for the field agents to try to maximize their own weights by appropriately choosing the reporting strategies that they report to the manager. Based on this feedback each report can be evaluated in the near future. The time interval between t and $t + 1$ is assumed to be as short as possible. Thus feedback provides the learning mechanism through which the organization can generate stable patterns of organizational behavior over time. Table 1 summarizes the procedures the field agents and the manager use to process information.

At time t, m receives $\boldsymbol{r} = (r_1,...,r_n)$ and aggregates it to μ_m by using d_m. Then m reports r_m based on $g_m(A)$ and μ_m. At $t + 1$, m observes event A and then updates d_m based on the state, $A = 0$ or 1, and $\boldsymbol{r}$. w_i would be revised by the degree how r_i is approached to the true value of event A, with regard to r_j, $j \neq i$. If a_i reports $r_i = 1$, and $A = 1$, a_i can increase w_i at $t + 1$ with $w_i^{t+1} \geq w_i^t$. Since w_i is decided with regards to r_j, even though a_i reports $r_i = 1$ (or 0) when $A = 1$ (or 0), if all of the other field agents report the same, then w_i^{t+1} is the same as w_i^t. The general principle is that the more accurate r_i, the heavier the weight that will be assigned to r_i. The updating rule for weights (see Bayarri and DeGroot 1988) is that:

$$\text{If } A = 1, \qquad w_i^{t+1} = \frac{w_i^t r_i^t}{\sum w_i^t r_i^t},$$

$$\text{if } A = 0, \qquad w_i^{t+1} = \frac{w_i^t(1 - r_i^t)}{\sum w_i^t(1 - r_i^t)}, \qquad 0 \leq w_i \leq 1, \ i = 1,...,n.$$

For example, let us assume that there are 3 field agents, (a_1, a_2, a_3). At time t, m assigns an equal weight to each agent, $w_i = 1/3$. Manager m receives $\boldsymbol{r} = (r_1, r_2, r_3) = (\beta_1(9,1), \beta_2(7,3), \beta_3(4,6))$. So by using d_m, m gets $\mu_m = 1/3(9/10) + 1/3(7/10) + 1/3(4/10)$

= .67. If $g_m(A)$ is diffuse, then m reports that the probability of the occurrence of event A at $t + 1$ is .67. If at $t + 1$ event A has actually occurred, then m updates d_m such as $w_1^{t+1} = [1/3(9/10) \div 20/30] = .45$, $w_2^{t+1} = .35$, $w_3^{t+1} = .2$. When m aggregates the reports at $t + 1$, he would use the updated weights, $w = (.45, .35, .2)$. Since r_1 is more accurate than the others, w_1 is heavier than the others, while r_3 receives less weight.

3.3 Principles in information processing

We can consider the following criteria in information processing for comparing different models of organizational structure.

A1. Information cost

Information cost, IC, means the overall cost to the organization of information processing. This involves the cost of observing the environment, analyzing reports, and making an organizational report. The information cost of an organization is the sum of the managers' information processing costs and of the field agents' observation costs. It is assumed that the unit cost of observing a sample from the environment, (c), is the same for different organizational structures. It is also assumed that the greater the structural level of a manager, the greater is the unit cost of analyzing a report.[9] For example, the top manager's unit cost of analyzing a report is greater than a division manager's. The information cost for the manager (ic_m) is a function of the structural level of that manager,

9 Starbuck (1971) explained the reason why the span of control near the top of the hierarchy is supposed to be smaller than near the bottom is there is greater need for coordination near the top.

L_m, and the number of reports to that position, N(r).[10] It will be an exponential function because the information cost will be geometrically increased by receiving more reports. As receiving one more report, the manager needs not only to analyze it but also to compare it with the others. The field agent's information cost (ic_i) is the simple product of the number of observations, o_i, times the unit cost of observation, c. Therefore, the information cost of an organization is:

$$\mathrm{IC} = \sum ic_m + \sum ic_i = \sum L_m^{\mathrm{N}(r)} + \sum c \cdot o_i$$
where c is constant, $c > 0$, $m = 1,...,r$, $i = 1,...,n$.

This functional form for IC represents that the total information cost of an organizational structure is the sum of information costs of the managers and the field agents. For example, if a division manager receives 3 reports from his subordinates, then his information cost is $2^3 = 8$. If a field agent observes 12 samples from the environment, his information cost is $12c$. If all the organizational structures have the same n numbers of field agents who generate the same k number of observations, then $\sum ic_i = c \cdot n \cdot k$ is the same for all the organizational structures.

Let us call IC(·) the information cost in an organization. Then h is preferred to g iff the information cost of h is less than that of g:

$$h \text{ P } g \quad \text{iff } \mathrm{IC}(h) < \mathrm{IC}(g).$$

10 Williamson (1970) considered two variables to represent organization costs: the span of control, and the number of hierarchical levels.

A2. Event predictability

Event predictability is the fundamental criterion for comparing organizational structures in information processing. It refers to how accurate the organizational prediction of event *A* is. It is defined as the absolute value of the difference, or deviation, between the organizational prediction on event *A*, r_o, and the actual state of event *A*. However, it cannot be known until the organization observes the actual state of event *A*. Furthermore, it can vary at each time when the organization knows the state of the event. It can be estimated by considering the variables which are closely related with event predictability. For estimating event predictability, the basic condition is that the information received from field agents is accurate and unbiased. Managers should use a certain kind of incentive mechanism to insure honest information transmission from the subordinates. Under the condition where an appropriate incentive mechanism is used, information predictability is estimated as a function of both information efficiency and information reliability.

A2.1. Information efficiency

Information efficiency refers to the size of the sample an organization uses to estimate *A* from the environment. According to the probability theory, if the observations themselves are accurate, the more observations an organization generates, the more accurately the organization predicts the event. If one has detailed information about his jurisdiction, the associated probability interval would be narrow. Let us call two different organizational structures *h* and *g*, and the number of observations which an organization generates as N(·). Then h is preferred to g iff the number of observations in h is greater than that in g:

h P g iff $N(h) > N(g)$.

A2.2. Information reliability

Information reliability refers to how much agreement there is within an organization about the probability of event A. The more agreement about this probability, the more reliable the organization believes the prediction to be, and the more objective is the probability. Let us call AN(·) the number of similar reports in an organization. h is preferred to g iff the number of similar reports in h is greater than that in g:

h P g iff $AN(h) > AN(g)$.

The more information efficiency, the more event predictability, and that the more information reliability, the more event predictability. Therefore, event predictability is proportional to both information efficiency and information reliability. I assume that event predictability, EP $\propto N^{AN}$. This functional form for EP represents that EP can be estimated with the number of observations and the number of major agreements on the probability. It shows that EP will increase when increasing the number of observations, and when achieving more agreements about the probability. Let us call event predictability in an organization EP(·). h is preferred to g iff the information predictability of h is greater than that of g:

$$EP = 1 - |A - r_o| \propto f(N, AN), \qquad A = \{0, 1\}.$$

$$EP \propto N^{AN}.$$

$h \text{ P } g$ iff $\text{EP}(h) > \text{EP}(g)$.

A.3. The tradeoff between information cost and event predictability

The goal of the top manager is to design an organizational structure which can minimize information cost and maximize event predictability. However, if it is impossible to satisfy these two principles simultaneously, he would make a trade-off between these principles. If information cost is more critical than event predictability, he would choose the organizational structure which can reduce information cost. On the other hand, if event predictability is more critical, he would design the organizational structure which would maximize event predictability even while paying more information cost. The top manager's choice (*ch*) of an organizational structure is based on the overall information cost and on the event predictability of an organization.

$$ch = f(\text{IC}, \text{EP}) = \frac{\text{EP}}{\text{IC}}$$

This functional form for *ch* represents that the value of *ch* will vary directly with EP and inversely with IC. The value of *ch* will be increased when EP is increased, and proportionally decreased when IC is increased.

3.4 An information processing game

Information processing in an organization is subject to the strategic behavior of subordinates (Simon 1976, Cyert and March 1963). Information is the only factor that determines the individual's relative weight and utility. "In reporting at every level, hierarchy is conducive to concealment and misrepresentation" (Wilensky 1967, p.43). Cyert and March (1963) stated:

> Where different parts of the organization have responsibility for different pieces of information relevant to a decision, we would expect some bias in information transmitted due to perceptual differences among the subunits and some attempts to manipulate information as a device for manipulating the decision (p.67).

O'Reilly and Roberts (1974) investigated the directionality of information flows in organizations and the impact of trust and influence on these flows. The study showed that more favorable information is passed upward, while unfavorable but important information is passed laterally. But they also found that upward information filtration is heavily influenced by trust between superior and subordinate. Thus to solve the problem of information distortion and misrepresentation it is necessary to employ a mechanism or relationship that would ensure honest reporting. In the case of public good provision, Groves and Loeb (1975) studied the mechanisms which provide an incentive for each individual to send truthful information, so that an optimal quantity of the public input will be provided by the coordinator. Under this mechanism each individual will be charged the difference between the budget and the reported benefits of the other individuals. Since misrepresentation cannot give any advantage, truth telling will be the dominant strategy.[11] Groves and Ledyard (1977) explained:

> Even though consumers are completely free to misrepresent their demands for public goods, the tax and allocation rules are structured in such a way that in equilibrium it is in each consumer's individual self-interest to reveal

[11] In a Groves mechanism the dominant strategy of the subordinate is truth telling, but that of the manager will be misrepresentation since it cannot consider the designer's strategic behavior (Hammond and Miller 1989, Miller 1992). Miller (1992) suggested that it is necessary that the manager credibly commits himself to these efficient incentive schemes.

his true demand or valuation of the public good (p.783).

But the Groves mechanism cannot balance the budget and so reaches nonoptimal outcomes. d'Aspremont and Gerard-Varet (1979a) indicated, using Bayesian approach to incomplete information, that if a compatibility condition is imposed on individual beliefs, and if a Bayesian solution is given to the incentive problem, then one may find mechanisms to simultaneously ensure incentive comparability and budget balancing. This section will search for an incentive mechanism through which information processing is immune to the strategic use of information.

An organizational structure can be thought of as a vector of equilibrium strategies in a non-cooperative game (see Dow 1990). A noncooperative game is a game in which the individual's optimal decisions depend on his beliefs about the play of his opponents. The concept of a Nash equilibrium plays a central role in a noncooperative game. The way to approach Nash equilibrium is to propose a strategy combination and test whether each player's strategy is a best response to the other's strategies.

Information processing in the organization can be analyzed by an extensive form game since it contains the following information:

(1) the set of players
(2) the order of moves--i.e., who moves when
(3) the players' payoffs as a function of the moves that were made
(4) what the players' choices are when they move
(5) what each player knows when he makes his choices
(6) the probability distributions over any exogenous events (Fudenberg and Tirole 1991a, p.77).

For extensive form games, the concept of Nash equilibrium is not sufficient since: (1) Nash criterion does not require players to make nondominated choices in equilibrium;

(2) there is nothing strictly irrational about choosing weakly dominated strategies (Bernheim 1984, Pearce 1984); and (3) Nash equilibrium may involve unreasonable behavior at unreached parts of the extensive form (Van Damme 1983, Fudenberg and Tirole 1991a, ch.3). Thus much effort has been focused upon refining the concept of Nash equilibrium. One of the equilibrium refinements is the concept of perfect Bayesian equilibrium. Perfect Bayesian equilibrium results from combining the ideas of subgame perfection, Bayesian equilibrium and bayesian inference. The information processing game would be analyzed by applying the concept of perfect Bayesian equilibrium (Fudenberg and Tirole 1991b).

Information processing in an organization should be sequentially iterated through a time dimension. I assume that information processing is continuous through time dimension as $t \to \infty$, and the time interval between t and $t + 1$ is as short as possible.[12] The game at time t would be affected by the previous game at time t - 1, and would influence to the next game at time $t + 1$. An information processing game will be defined as following.

Let N = $\{a_1,...,a_n, m\}$ be the set of players, who are n field agents, and a manager. For deep structures, an organization game would be analyzed as a two stage game -- with a_i and dm, and with dm_i and tm. In the game **G**, let us assume:

1. There is a given organizational structure Ψ from time $t = 0$.

2. At each time t, a_i has a subjective probability distribution function over the

12 In this kind of multi-time information processing game, we can also consider the other dimensions such as discount factors and risk preferences. When including these dimensions into the game, the reporting strategies of field agents may be more specified with different types of field agents. But these issues remain to be considered.

states of event A. It is independent with each other. a_i would have his posterior probability distribution, $p_i(A)$, based on his prior, $g_i(A)$, and his likelihood function, $l_i(o_i)$. The prior is continuously revised by the posterior and the state of event A. a_i would update his probability distribution function through the time dimension by applying Bayes rule:

$$p_i(A) = f(g_i(A), l_i(o_i)), \qquad g_i(A)^{t+1} = f(p_i(A)^t, A).$$

3. At each time t, a_i would choose a reporting strategy function, r_i, based on $p_i(A)$ and his belief, b_i, on the manager's information aggregation strategies and the other agents' reporting strategies. Basically the agent's possible strategies are to report his own posterior probability distribution honestly, $r_i = p_i(A)$, and to misrepresent his posterior probability distribution, $r_i \neq p_i(A)$. Before reporting r_i, a_i knows $p_i(A)$ not $p_j(A)$ nor r_j of the other agents, $j \neq i$.

$$r_i\colon p_i(A) \rightarrow [0, 1].$$

4. For both a_i and m, the belief b should be consistent with Bayes' rule by depending on the previous history of the information processing and aggregation until t - 1, h^{t-1}, and the given strategies:

$$b = f(\cdot \mid h^{t-1}, \boldsymbol{r}, d_m).$$

5. a_i's utility $U_i(w_i)$ at t depends on the previous weight w_i^{t-1}, r_i and r_{-i}. At each time t, r_i should maximize his expected utility, $EU_i(w_i)$, before knowing the true state of event A.

6. At each time t, m would use a certain aggregation method for aggregating $\boldsymbol{r}$ and update it by which w_i^{t+1} would be revised. m would choose an aggregation strategy which should maximize his expected utility EU_m. m has his own belief on $\boldsymbol{r}$.

7. It is common knowledge that every player is a Bayesian player. Everybody knows that each player chooses a strategy that maximizes his expected utility given his belief, and each player updates his belief and probability distribution function.

8. The information processing game **G** is a multi-time game with $\boldsymbol{r}$ and d_m, where each a_i reports simultaneously in each time, and r_i at each time is transmitted before event A is actually occurred or not.

9. The strategies yield a Bayesian Nash equilibrium, if possible, not only for the whole game **G**, but also for any subgame **g** starting in each time t.

The states of event A are represented by the two values: $s(A) = \{0, 1\}$. a_i chooses a strategy (report) function $r_i(\cdot)\colon p_i \rightarrow [0, 1]$ from his strategy space $\boldsymbol{r}_i = \{r_i(\cdot)\}$. m chooses an aggregation rule, $d(\cdot)\colon[0, 1]^n \rightarrow [0, 1]$ from his aggregation strategy $\boldsymbol{d} = \{d(\cdot)\}$. Let us define a_i's utility as $U_i = f(w_i) = f(r_i, r_{-i}, w^{t-1})$. m's utility is defined as $U_m = f(d_m, ic, ep)$.

For all a_i, given aggregation rule d_m and given organizational structure Ψ,

$$\max EU_i(r_i, r_{-i}, w^{t-1} \mid d_m, \Psi)$$

$$= \max \sum p(s)U_i(r_i, r_{-i}, w^{t-1} \mid d_m, \Psi).$$

For m, given the set of reports $\boldsymbol{r}$ and given organizational structure Ψ,

$$\max EU_m(d_m, ic, ep \mid \boldsymbol{r}, \Psi)$$

$$= \max \sum p(s)U_m(d, ic, ep \mid \boldsymbol{r}, \Psi).$$

In a Bayesian game, the criterion for the best strategy is that it should give a player the highest expected utility. Expected utility is computed by multiplying utilities times probabilities and then adding them all together (Myerson 1985). The Bayesian equilibrium is defined as the combination of strategies and beliefs where neither field agents nor the manager can gain more by playing differently, given an organizational structure.

Definition 1. Perfect Bayesian equilibrium in the information processing game

A perfect Bayesian equilibrium (PBE) of a multi-time information processing game is an assessment $(\boldsymbol{r}^*, d_m^*, \boldsymbol{b})$ such that at any time t and under Ψ,

1. $(\boldsymbol{r}^*, d_m^*, \boldsymbol{b})$ is reasonable by satisfying the assumptions,
2. for each time t and the history h^{t-1}, the strategies for the remainder of the game are a Bayesian equilibrium given the beliefs.

$\forall\ a_i,\quad EU_i(r^*_i, r^*_{-i} \mid b_i, d^*, \Psi) \quad \geq \quad EU_i(r_i, r^*_{-i} \mid b_i, d^*, \Psi).$

$\forall\ m,\quad EU_m(d_m^* \mid b_m, r^*, \Psi) \quad \geq \quad EU_m(d_m \mid b_m, r^*, \Psi).$

For the manager to maximize his expected utility by improving information predictability, he should give his subordinates the correct incentives to reveal their posterior probability distribution honestly. To the extent that his private information on event A affects the decision of the manager, any field agent may find it advantageous to distort the information he transmits since he cannot be compelled to reveal it honestly without the correct incentives (d'Aspremont and Gérard-Varet 1979b).

Let us examine whether the relative weight rule, the aggregation rule of the manager, can give each field agent the correct incentives. If, under the relative weight rule, by reporting their posterior probability distributions honestly, all field agents can get more expected utility than by the other reporting strategies, the relative weight rule can compel honest reports. If so, we can call it a Bayesian incentive compatible mechanism.

Definition 2. Bayesian incentive compatible mechanism

A mechanism Ξ will describe the relative weight aggregation rule of the manager, d_m^*, and the vector of the agents' relative weight, w, that is, $\Xi = \langle d_m^*, w\rangle$ (see d'Aspremont and Gérard-Varet 1979b, 1982, Myerson 1985, d'Aspremont, Crémer and Gérard-Varet 1990). We denote by r^*_i the honest strategy for field agent a_i, such that $r^*_i = p_i(A)$ for all $p_i \in \mathbf{p}_i$. A mechanism Ξ is Bayesian incentive compatible iff it is a Bayesian equilibrium for all field agents to report their posterior probability distributions honestly such that

$\forall\ a_i,\quad w_i(r^*_i, r^*_{-i} \mid d_m^*) \ \geq\ w_i(r_i, r^*_{-i} \mid d^*_m),$

where $r^*_i = p_i(A)$, $r_i \neq p_i(A)$, and $r^*_{-i} = p_{-i}(A)$.

Theorem 1: The mechanism Ξ is Bayesian incentive compatible with the given utility function of the field agents.

Proof: For a_i, the goal is to maximize the expected utility by appropriately choosing r_i at any time t (see Bayarri and DeGroot 1988). For notational simplicity, $p = p_i(A)$ at t.

$$\max EU_i$$

$$\max \quad E(\log \frac{w_i}{\sum w_j})$$

$$\max\ [pU_i(w_i(r_i, A = 1)) + (1 - p)U_i(w_i(r_i, A = 0))] \quad , A = \{0, 1\}.$$

m assigns w_i at t based on w_i at t - 1 and on $\boldsymbol{r}$ at t such that[13]:

$$\text{If } A = 1, \quad w_i^t = \frac{w_i^{t-1} r_i^t}{\sum w_j^{t-1} r_j^t} \quad , i \neq j, \qquad w_i + \sum w_j = 1,$$

$$\text{if } A = 0, \quad w_i^t = \frac{w_i^{t-1}(1 - r_i^t)}{\sum w_j^{t-1}(1 - r_j^t)}.$$

$$E(\log \frac{w_i^t}{\sum w_j^t}) = p\log \frac{w_i^{t-1} r_i^t}{\sum w_j^{t-1} r_j^t} + (1 - p)\log \frac{w_i^{t-1}(1 - r_i^t)}{\sum w_j^{t-1}(1 - r_j^t)}$$

$$= p\log r_i^t + (1 - p)\log(1 - r_i^t) + (\text{terms not involving } r_i)$$

To maximize the expected utility, let us get the first order condition.

$$\frac{\partial E}{\partial r_i^t} (\log \frac{w_i^t}{\sum w_j^t}) = \frac{p}{r_i^t} - \frac{(1 - p)}{(1 - r_i^t)}$$

When $[\partial E/\partial r_i^t] = 0$, r_i^t may maximize or minimize the expected utility.

$$[p/r_i^t] - [(1 - p)/(1 - r_i^t)] = 0$$

$$p - pr_i^t + pr_i^t - r_i^t = 0$$

$$r_i^t = p.$$

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13 t or t - 1 is not a multiplier but means a certain point in time dimension.

If the second derivative of r_i^t is less than zero, that is, $\partial[\partial E/\partial r_i^t] < 0$, than we can say that r_i^t would maximize the expected utility when $r_i^t = p$.

$$\partial[\partial E/\partial r_i^t] \ = \ (-p + p - 1) \ < \ 0.$$

Thus when $r_i^t = p$, a_i can maximize the expected utility. Since $p = p_i(A)$ at t, r_i^t should be a_i's honest posterior probability distribution on event A.

$r^*_i = p_i(A)$ and the mechanism $\Xi = <d^*_m, w>$ is Bayesian incentive compatible. QED.

In the perfect Bayesian equilibrium of the information processing game, the dominant strategy of the field agent is to report honestly. That of the manager is to use the relative weight rule appropriately.[14] The existence of the relative weight rule as a Bayesian incentive compatible mechanism provides a common basis when comparing different organizational structures since it makes us expect that all subordinates will behave sincerely.

The problem of organizational design is viewed in terms of information aggregation. To design an organizational structure is to determine a set of information aggregation rules in consideration of the two principles, information cost and information predictability.

14 Theoretical equilibrium is never attained in reality, but the analysis of equilibrium conditions helps specify the behavioral tendencies in organizations. These behavioral tendencies can be used to make predictions (Barney 1990).

4. Information Processing in Organizational Structures

4.1 Four models of organizational structures

This chapter will analyze and compare the processing and aggregation of information within different organizational structures. It will generate four simple models of organizational structures, and discuss the characteristics of, and the advantages and disadvantages of, each kind of organizational structures in information processing. Then these four structures will be compared with each other.

Organizational structure defines the lines of authority and communication between individuals and divisions, as well as information transmission through these lines of communication and authority (see Gulick 1937, Chandler 1962, Galbraith 1977, Mintzberg 1979, Child 1984, Hammond 1986). Organizational structure serves to produce organizational outputs, to regulate the influence of individual variations, and to ensure that individuals conform to the requirements of the organization (Hall 1982). An organizational structure has essentially two objectives: it facilitates the flow of information within the organization in order to reduce the uncertainty in decision making; and it achieves effective coordination-integration (Duncan 1979). In this study, organizational structure is defined as the hierarchical rules governing how information processing and aggregation must take place. The design of an organizational structure determines a certain set of information processing and aggregation routes.

The focus here will be on two dimensions of organizational structure which affecting information processing and aggregation: specialization and coordination (Gulick

1937, Chandler 1962, Galbraith and Nathanson 1978).[1] Specialization is dividing the work of the organization into divisions or individuals for efficient performance. Coordination is integrating the activities of specialized divisions or individuals in order to achieve organizational objectives: "Coordination involves fitting together the activities of organization members, and the need for it arises from the interdependent nature of the activities that organization members perform." (Argote 1982, p.423). Both dimensions are essential to effective information processing.

Four models of organizational structures will be created in order to test the effects of changes in structure on information processing. Based on the coordination principle, we can consider two kinds of organizational structures: "flat" and "tall" structures. As Child (1984, p.59) observes, "Tall and flat structures are usually identified by the number of hierarchical levels there are in an organization relative to its total size. A tall structure is one that has many levels in relation to total numbers employed, while a flat structure is one that has few levels relative to total employees." Based on the specialization principle, we can consider two kinds of matching problems: "one-to-one" and "one-to many" matching. This refers to the choice of a particular form of the organization's interaction with its environment (Baligh and Burton 1980). As organizations become more specialized, they have to achieve more coordination. Balancing specialization and coordination is the key to designing effective organizational structures.

One-to-one matching assigns a separate jurisdiction to each field agent. It

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1 Similar principles in organizational design are "differentiation" and "integration" (Lawrence and Lorsch 1967).

promotes organizational efficiency in the sense that the more observations the organization generates with the same information cost, the more efficient it is. Specialization increases as jobs are broken down into more simple components (Dewar and Simet 1981). If the environment can be decomposed into many subsets, $E_1,\ldots,E_n$, the organization can greatly speed up its information generation by assigning each field agent, a_i, to each subenvironment, E_i. Specialization by one-to-one matching enables field agents to become experts in their jurisdictions. They are relying less on individual biases and more on empirical observations. The negative aspect of specialization is that it gives each field agent informational monopolistic power on each jurisdiction since the organization can get access to the information on E_i only through a_i.

One-to-many matching assigns a common jurisdiction to all field agents. The purpose is organizational reliability (Landau 1969, Bendor 1985, Lerner 1986, Heimann 1992). Landau (1969) argues that we can decrease the probability of organizational failure and increase organizational reliability by using redundant factors (see Bendor 1985, Heimann 1992). Redundancy in information processing occurs when some portion of information is produced from a common jurisdiction. The other aspect of redundancy is that it makes field agents compete with each other, since the information from the environment is pooled, as they try to prepare the best possible estimate of event A.

The structural arrangements that produce redundancy are grouped into two basic categories, "duplication" and "overlap":

> Duplication provides redundancy by emphasizing parallelism. Overlap provides redundancy by emphasizing ambiguity. The ambiguity is in the jurisdictions of the overlapping units. Define jurisdictions as organizationally mandated functions in designated task areas assigned to

> a unit. In overlap *some* of the functions assigned to A are also assigned to B. Thus overlap ought really to be called "partial overlap". By contrast in duplication *all* the assigned functions of A and B are identical; A and B are completely interchangeable (Lerner 1986, p.336, italics in original).

Duplication is the simplest form of redundancy (1991). It makes the comparison of reports from a common jurisdiction easier, while with an overlapping jurisdiction it is difficult to figure out what portion of reports are produced from a common area. Thus in this study duplication is adopted as the structural arrangement of redundancy. In one-to-one matching each field agent has his own jurisdictional area, while one-to-many matching is a duplication of jurisdiction in which all field agents have the same jurisdiction.

The taller an organizational structure, the more emphasis on intermediate coordination processes, while the flatter an organizational structure, the lower the degree of information distortion (Worthy 1950, Melzer and Salter 1962, Wilensky 1967, Carzo and Yanouzas 1969). A tall structure means that there exist intermediate aggregation procedures between the field agents and the top manager. There is a delegation of some information aggregation tasks to lower levels of the organizational structure. This reduces information costs for the top manager but risks distortion in information processing. A flat structure exists when there are direct information routes between the field agents and the top manager. There is no interruption or deterioration in information processing, but it imposes more information costs on the top manager when analyzing the reports.

Distinguishing between tall and flat structures, and between one-to-one matching and one-to-many matching yields four different kinds of organizational structures for information processing. The characteristics of each will be analyzed.

Table 2: Four Models of Organizational Structure

	Flat Structure	Tall Structure
One-to-one matching	**Flat one-to-one structure**	**Tall one-to-one structure**
One-to-many matching	**Flat one-to-many structure**	**Tall one-to-many structure**

4.2 Flat one-to-one structure

A flat one-to-one structure consists of one top manager, *tm*, and a number of field agents, a_i, $i = 1,...,n$. Each a_i has his own jurisdiction and observes a sector E_i from which he can get information on A_i. Based on his observation of E_i, each a_i produces a report r_i, and send it to *tm*, who aggregates r_i and makes an organizational report.

The environment E would be segmented into separated jurisdictions, E_i. It facilitates increased specialization (Duncan 1979). Thus the field agent a_i generates information based on the observations in his jurisdiction E_i. As a Bayesian player, the field agent has his own prior estimate of the probability of event A, $g_i(A)$, and the likelihood function of event A based on his information gathering. The field agent's posterior probability is based on his prior and on his observations of his jurisdiction. Whenever he receives information, he evaluates whether it indicates the occurrence of event A. Each a_i constructs his own beta probability distribution function of event A, i.e., $p_i(A) = f(g_i(A), l_i(E_i))$.

Each a_i observes his jurisdiction continuously, and gathers a certain amount of information at each time. Since he has a restricted jurisdiction, he can cumulate his knowledge on his jurisdiction through continuous observations so that he can analyze data more precisely. He gathers more samples from his jurisdiction, and he is gradually

relying more on the objective observations on E_i. If he accumulates detailed information about the same E_i, its associated probability interval about event A would be narrow: a larger sample contains more information about the jurisdiction and hence allows more precise estimation. Since a_i can have a narrow focus on E_i and can draw a large sample from E_i, it is expected that a_i's posterior probability distribution function on A_i will be narrow and sharply peaked, and thus have lower variance. Based on his posterior probability, the field agent would report r_i to the top manager.

Since each field agent has his own jurisdiction, each report is based on observations from different segments of the environment. Each field agent makes o_i observations of data from E_i. So the total numbers of observations on E in this structure would be $\sum o_i$, $i = 1,\ldots,n$. If all the field agents observe the same k number of data from each jurisdiction E_i, then the total number of observations in this structure would be nk. This structure thus transmits n reports to the top manager.

A field agent may behave strategically because a field agent with an independent jurisdiction has some power from his information monopoly. This is because each field agent can easily distort information without arousing the suspicion of the other field agents. Even though the report may be doubted by the top manager, the field agent can persuade the top manager by demonstrating his expertise on that jurisdiction. This power, based on information monopoly and expertise on his jurisdiction, might allow all field agents to behave strategically, and each field agent might use his own power to maximize his relative weight on information aggregation. If the field agent a_i expects that a strategic report ($r_i \neq p_i(A)$) will provide him more expected utility than a sincere report

(r_i = $p_i(A)$), he will not tell truth; that is, $r_i \neq p_i(A)$ if $w_i(r_i \neq p_i(A)) > w_i(r_i = p_i(A))$, and $r_i = p_i(A)$ if $w_i(r_i = p_i(A)) \geq w_i(r_i \neq p_i(A))$. The top manager needs to give field agents an incentive for honest reporting. Therefore, the top manager will apply the relative weight rule as an Bayesian incentive compatible mechanism.

[Figure 1 about here]

The top manager is the only one responsible for coordination in this flat one-to-one structure. The top manager takes responsibility for the synthesis of all specialized inputs. The major role of the top manager in this structure is to decide how to assign the relative weights to the reports. The top manager receives the reports from all the field agents and aggregates them into a likelihood estimate of event *A*. Since there are the direct reporting routes between the *n* field agents and the top manager, the top manager must analyze and compare all *n* reports. When he applies the relative weight rule, he needs to allocate a weight to each report. He will incur great information costs if the number of field agents is large. The information *tm* receives is $\sum r_i = \sum f(g_i(A), l_i(E_i))$ and he assigns $w_i = f(w_i^{t-1}, w_j^{t-1}, r_i, r_j), i \neq j$. By using the reports from the field agents and his aggregation method, the top manager constructs his likelihood, that is, $\mu_{tm} = \sum w_i r_i$.[2] Then the top manager makes the organizational report on event *A*, based on his prior and

[2] The relative importance of jurisdiction can be considered in information aggregation. Sometimes not all jurisdictions are equally important in the final evaluation of the event. In this case, the top manager needs to modify the relative weight rule to include a factor on jurisdictional importance. But in this study I assume that all jurisdictions have equal importance since for analyzing how organizational structures affect information processing and aggregation it is necessary to fix the other factors constant. The other purpose of the relative weight rule is to ensure honest reporting that is the basic condition of comparing organizational structures. However, I expect that even with somewhat different form combining jurisdictional importance, the relative weight rule is still useful for both aggregating information and ensuring sincere reporting because jurisdictional importance is not controlled by field agents but determined by the top manager. It will be discussed further in the conclusion chapter.

this likelihood. The process of making the organizational report is: $\sum f(g_i(A), l_i(E_i)) \rightarrow \mu_{tm}$ with $g_{tm}(A) \rightarrow r_{tm} = f(g_{tm}(A), \mu_{tm}) = f(g_{tm}(A), l_{tm}(E))$. At this point, the probability reports from the different jurisdictions can be combined into a single probability based on the whole environment: $[0, 1]^n \rightarrow [0, 1]$.

Feedback functions to enforce the relative weight rule to work effectively. The field agents will report truthful estimates because the Bayesian incentive compatible mechanism ensures $w_i(r_i = p_i(A)) \geq w_i(r_i \neq p_i(A))$, as shown by Theorem 1. The only way to maximize the expected utility is to report honestly as $r_i = p_i(A)$. Based on the deviation between a field agent's estimate of the probability of event A and the actual state of event A, the top manager would revise the relative weight of the field agents. Both the top manager and the field agents may update their prior beliefs through feedback. They may compare their estimates and the actual state of the event, and adjust their prior beliefs. Based on the change in his relative weight, the field agent can revise his information evaluation method by examining whether he interpreted the data precisely. The information processing in flat one-to-one structure would be summarized as Figure 2.

[Figure 2 about here]

When the top manager evaluates this structure and compares it with the other alternatives, he would focus on the two principles--information cost and event predictability. The overall information cost of this organizational structure is the sum of the top manager's information processing costs and of the field agents' observation costs. The unit cost of analyzing intelligence from the environment is assumed to be constant. The field agent's information cost (ic_i) is the product of the number of observations, o_i,

and the unit cost of an observation, c. Thus, $ic_i = c \cdot o_i$. For n field agents, the sum of observation costs is $(\sum c \cdot o_i,\ i = 1,...,n)$. The top manager needs to analyze and compare all the reports from the field agents. The first determinant of the top manager's information cost is the number of reports, which is the same as the number of the field agents in this structure. Since this structure generates n reports at each time and it has only two levels of hierarchy, the top manager's information processing cost is 2^n. Thus the total information cost of this structure is $(2^n + c\sum o_i,\ i = 1,...,n)$. If all field agents observe the same k number of data from the jurisdictions, and $c = 1$, the information cost would be $(2^n + nk)$.

Given the existence of the Bayesian incentive mechanism, each field agent would report $r_i = p_i(A)$. Then event predictability can be estimated by the function of both information efficiency and information reliability. This structure emphasizes information efficiency since it is increased by a specialization of the jurisdiction of a field agent. Information efficiency is based on the number of observations, N, which this organization generates. It is $(N = \sum o_i)$ when o_i is the number of observations of a_i. Since event predictability cannot be known until observing the state of event A at the next time, and each time it may be varied, it cannot be directly estimated. However, it can be evaluated by calculating its expected value. The expected value of event predictability is proportional to the function of information efficiency and information reliability, as EP $\propto N^{AN}$, as defined in Chapter 3. The expected value of EP of this structure is supposed to be proportional to a certain point on the interval $[\sum o_i, (\sum o_i)^n]$. If all the field agents generate the same k data, then the interval would be $[nk, (nk)^n]$.

The advantages of this flat one-to-one structure are: (1) information gathering can be more efficiently performed if the environment of-the-whole is decomposed into a certain number of separated jurisdictions for matching each jurisdiction with each field agent; that is, E_i with a_i, and if the field agent is allowed to specialize in each jurisdiction; and (2) there is less procedural error since the top manager can get access to the information from the field agents without any filtration or distortion.

The top manager of this flat one-to-one structure has a more deterministic role in information processing than the other models since (1) there is only one position to aggregate the reports and only the top manager can manage information aggregation; and (2) the top manager is the only one who has a broad viewpoint on the whole environment E. The top manager has a greater breadth of information about the environment than the field agents, while the latter have more detailed information about their own jurisdictions.

4.3. Flat one-to-many structure

A flat one-to-many structure consists of one top manager, *tm*, and a number of field agents, a_i, $i = 1,...,n$. All a_i observe the same portion of all sectors of E, that is, $\boldsymbol{e}_i = (e_1,...,e_n)$, $e_i \in E_i$, $\boldsymbol{e}_i \in E$, $\boldsymbol{e} = \boldsymbol{e}_i = \boldsymbol{e}_j$, $i \neq j$.

Each portion of environment $\boldsymbol{e}$ would be observed by all field agents. Each field agent a_i generates information based on his observations of the common jurisdiction. Thus the jurisdiction would be scrutinized from n different perspectives. Even though all observe the same jurisdiction, the estimates might be different because each field agent has his own method of observation and analysis. For example, a_i and a_j, $i \neq j$, observe

the same intelligence. One possible result might be that a_i evaluates it as evidence for the possible occurrence of the event, while a_j decides that it indicates the event will not happen. Thus even with $\boldsymbol{e}$, $l_i(\boldsymbol{e})$ might be different from $l_j(\boldsymbol{e})$. On the other hand, a_i and a_j might draw the same conclusion from $\boldsymbol{e}$.

As a Bayesian player, the field agent has his own prior belief on the probability of event A. He then gathers some information from the environment, and constructs his posterior probability distribution function of event A as $p_i(A) = f(g_i(A), l_i(\boldsymbol{e}))$. Since a_i makes only a small number of observations on each e_i, a_i's probability distribution function on A is broad--it comes all of E--but shallow. Based on his posterior probability, the field agent would report r_i to the top manager.

Since all the field agents have a common jurisdiction, all reports are based on the same observations with different estimation methods. Thus if $r_i(A)$ is the same as $r_j(A)$, information is more reliable since there is a consensus between the two different estimations. $\sum r_i(A)$ would be the sum of independent evaluations on the same data. In this structure, each field agent observes o number of data, $o = o_i = o_j$, $i \neq j$, from the environment $\boldsymbol{e}$, and thus the total number of observations of this structure is the same as the number of an individual's observations o because of the duplication effect. If a_i gathers k sample data from $\boldsymbol{e}$, the total number of observations in this structure would be k since all field agents get the same data, but each a_i may interpret the data differently. The reduction in the effective sample size, compared to one-to-one structure, results in more weight being given to the prior probability in the computation of the posterior probability (Winkler 1985). On the whole, the set of the reports from the field agents would cover only the shallow and broad observations on the environment. Also for E_i, it gathers only k/n data.

[Figure 3 about here]

The top manager's role in this structure is to synthesize the different points of view. Since the field agent gets information on all dimensions of the event, the differences in the reports from the field agents indicate the differences in their subjective interpretations of the event. Thus, information aggregation by the top manager is focused on the coordination of the different evaluations. If there is consensus among the field agents' reports, there is no need to analyze and compare the reports by the unanimity principle. Only the top manager needs to announce the agreed probability as the organizational report. But if there is no consensus, the top manager will incur great information costs since he receives n number of reports. tm receives $\sum r_i = \sum f(g_i(A), l_i(e))$ and assigns $w_i = f(w_i^{t-1}, w_j^{t-1}, r_i, r_j), i \neq j$. By using the reports and his aggregation rule, the top manager arrives at his likelihood, $\mu_{tm} = \sum w_i r_i$. Then the top manager makes the organizational report on event A, by combining his prior belief and this likelihood. The process of making the organizational report is: $\sum f(g_i(A), l_i(e)) \rightarrow \mu_{tm}$ with $g_{tm}(A) \rightarrow r_{tm} = f(g_{tm}(A), \mu_{tm}) = f(g_{tm}(A), l_{tm}(e))$.

Feedback reinforces the Bayesian incentive compatible mechanism, and functions as the process to adjust the subjective perspectives of the field agents and the top manager on the event. Through the adjustment process the top manager may update the relative weights of field agents and his prior belief, and each field agent would revise his prior belief and estimation method. The information processing in flat one-to-many structure would be summarized as in Figure 4.

[Figure 4 about here]

The information cost of this organizational structure is the sum of the top manager's information processing costs and the field agents' observation costs. The unit cost of observing evidence from the environment is assumed to be constant. The field agent's information cost (ic_i) is the product of the number of observations, o, which is the same for all a_i and the unit cost of an observation, c. Because all field agents observe the same data from the duplicated jurisdiction, each must analyze them independently, and so each incurs an information cost. Thus, $ic_i = ic = c \cdot o$. For n field agents, the sum of observation costs is $n \cdot c \cdot o$. The top manager needs to analyze and compare all the reports from the field agents. The top manager's information cost is determined by the number of reports, which is the same as the number of the field agents in this structure. Since this structure generates n reports at each time and it has only two levels of hierarchy, the top manager's information processing cost is 2^n. For comparability, if all field agents observe the same k data and $c = 1$, the total information cost of this structure is $(2^n + n \cdot k)$.

Event predictability is proportional to the function of both information efficiency and information reliability. This structure emphasizes information reliability since it is increased by the duplication of the jurisdiction for all field agents. Information reliability is based on the number of similar reports in an organization. The more consensus on the state of the event the organization achieves, the more reliable the prediction is. The expected value of event predictability of this structure is proportional to N^{AN}, where N is the number of observations and AN is the number of same reports on the estimation. Thus, event predictability is proportional to a certain point on the range $[o, o^n]$. For comparability, if all the field agents generate k data, then the range would be $[k, k^n]$.

One aspect of this redundant structure is that with duplicating jurisdictions, the field agents compete against each other over maximizing their relative weights, and information is scrutinized from different perspectives. Thus, it benefits from diverse evaluation methods. This leads to more reliable reports since the field agents make the best estimates in competition and there may be more of a chance to achieve consensus on the probability of event A among field agents.

The other aspect of this redundancy is that this structure permits the field agents to predict the event by constructing posterior probabilities based on the environment $\boldsymbol{e}$. The function of information aggregation is basically distributed to the field agents. Thus there might be tensions among competing field agents or inner-bargaining among colluded field agents since their reports can be easily compared with each other.

The advantages of this flat one-to-many structure will be: (1) the reports from the field agents would be more reliable since there is the common jurisdiction and the field agents may try to make the best estimate of event A; (2) the field agents as well as the top manager are able to have a broader perspective on the environment and event A, and it offers the field agents greater scope and responsibility in their prediction; and (3) as in flat one-to-one structure, there is less procedural error in information processing since there is no filtration or distortion between the field agents and the top manager. By using the common jurisdiction, this structure seeks to benefit from the diverse views and judgments of field agents in predicting event A and provides means of identifying and correcting errors that would be undetectable in one-to-one structures.

The top manager has a less deterministic role in information processing since (1) all field agents as well as the top manager have a broader understanding on the environment and event A; and (2) the field agents share the role of information aggregation with the top manager.

4.4. Tall one-to-one structure

A tall one-to-one structure consists of one top manager, tm, several division managers, dm_j, $j = 1,...,v$, $v < n$, and a number of field agents, a_i, $i = 1,...,(n - v)$. The total number of the subordinates of the top manager is fixed as n as in the other organizational structures. The number of divisions is less than or equal to the number of field agents, $v \leq (n - v)$. Each division has $(n-v)/v$ field agents.[3] Each division has its own divisional environment, DE_j, in which each field agent in this division has his own jurisdiction, E_i. a_i observes E_i and processes r_i to dm_j who aggregates the reports and transmits a divisional report, dr_j, to tm. The tm then aggregates these reports and make a final evaluation on the occurrence of event A.

The information processing in this structure involves three factors: how the field agents generate information; how the division managers aggregate the reports; and how the top manager analyzes the divisional reports. The environment E would be segmented

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[3] For simplicity, it is assumed that each division has an equal number of field agents. However, unequal allocations of the field agents (e.g., Division 1 has 3 field agents, and Division 2 has 5) produce the same results. When $(n-v)/v$ is not integer, it means there is unequal allocations of field agents.

into separate jurisdictions, E_i, $i = 1,...,(n - v)$. An E_i might be larger than that in a flat one-to-one structure since $(n - v) < n$. The characteristics of information generation by the field agents are similar to those in a flat one-to-one structure. The field agent a_i generates information based on the observations on his jurisdiction E_i. As a Bayesian player, the field agent has his own prior information on the probability of event A, $g_i(A)$, and the likelihood function of event A based on his information gathering. Whenever he gets information, he evaluates whether it indicates the occurrence of event A. Since each field agent has his own prior belief on event A and his own method of evaluating information, he subjectively estimates the information from the jurisdiction. Each a_i constructs his own beta probability distribution function of event A, i.e., $p_i(A) = f(g_i(A), l_i(E_i))$. If a_i has detailed information about an area, its associated probability interval would be narrow. A larger sample contains more information about the jurisdiction and hence allows more precise estimation. Since a_i can have a narrow but deep focus on E_i but with a large sample from his jurisdiction, it is expected that a_i's posterior probability distribution function on A_i is narrow and sharply peaked and thus has the low rates of variance. Based on his posterior probability, the field agent would report r_i to the division manager.

[Figure 5 about here]

Since each field agent has his own jurisdiction, each report is based on the observations on a different segment of the environment. Thus even though $r_i(A)$ is the same as $r_j(A)$, each probability is based on a different jurisdiction, $E_i \neq E_j$, and a different evaluation method. Each field agent observes o_i number of data from E_i and then the total information generations in this structure would be $\sum o_i$, $i = 1,...,(n - v)$ on E. Thus the estimations on $\sum o_i$ would be included in $\sum r_i$ reports. If all the field agents observe the same k number of data from each jurisdiction, then the total number of observations in this structure would be $(n - v)k$. This structure transmits $(n - v)$ reports to the division managers.

Each division manager receives $(n - v)/v$ reports from the field agents in his division. A major function of division managers is the filtering and editing of information. The role of the division manager is to compare and analyze the reports based on his own perspective and to transmit the divisional report to the top manager. Each division manager has a broader viewpoint of the divisional environment, while the field agents have more detailed knowledge of their own jurisdictions. dm receives $\sum r_i = \sum f(g_i(A), l_i(E_i))$ and assigns $w_i = f(w_i^{t-1}, w_j^{t-1}, r_i, r_j)$, $i \neq j$. By combining the reports and his own aggregation rule, the division manager aggregates the reports, $\mu_{dm} = \sum w_i r_i$, $i = 1,...,(n - v)/v$. Then the division manager makes the divisional report on event A, based on his prior and this likelihood which is based on the divisional environment. The process of making the divisional report is: $\sum f(g_i(A), l_i(E_i)) \rightarrow \mu_{dm}$ with $g_{dm}(A) \rightarrow dr_j = f(g_{dm}(A), \mu_{dm}) = f(g_{dm}(A), l_{dm}(DE_j))$. At this stage, the probabilities based on the field agents' jurisdictions can be combined into the condensed probabilities based on the divisional environments: $[0, 1]^{(n-v)} \rightarrow [0, 1]^v$.

The top manager receives the reports from only the division managers. Since there are indirect reporting routes between the field agents and the top manager, the top manager can get access to only filtered and prescreened information. But this reduces the top manager's information processing cost since $v < n$. When the top manager applies the relative weight rule, he needs to allocate the weights to the divisions. Thus it might be easy to update the relative weights at each time since the number of the divisions is smaller than that of the field agents.

The *tm* receives $\sum dr_j = \sum f(g_{dm}(A), \mu_{dm}) = \sum f(g_{dm}(A), l_{dm}(DE_j))$. By using the reports from the division managers and his aggregation method, the top manager constructs his likelihood, that is, $\mu_{tm} = \sum w_j dr_j$. Then the top manager makes the organizational report on event A, based on his prior belief and this likelihood. The process of making the organizational report is: $\sum f(g_i(A), l_i(E_i)) \rightarrow \sum dr_j = f(g_{dm}(A), l_{dm}(DE_j)) \rightarrow \mu_{tm}$ with $g_{tm}(A) \rightarrow r_{tm} = f(g_{tm}(A), \mu_{tm}) = f(g_{tm}(A), l_{tm}(E))$. At this point, the probabilities based on the different divisional jurisdictions can be combined into the single probability based on the whole environment: $[0, 1]^{(n-v)} \rightarrow [0, 1]^v \rightarrow [0, 1]$.

Feedback in tall one-to-one structures has these three-stage procedures: (1) feedback from the actual state of the event; (2) feedback from the top manager to the division managers; and (3) feedback from the division manager to the field agents. By comparing his prediction with the actual state of the event, each actor might revise his prior belief and his estimation method. After observing the state of the event, the top manager would update the relative weights on the division managers and inform them of the revised ones. Based on the feedback from the state of the event and from the top manager, the division managers would adjust their perspectives on the divisional jurisdictions and also revise the relative weights of the field agents. Given the feedback from the division manager and the state of the event, the field agents would update their prior beliefs and information estimation methods. Information processing in tall one-to-one structure is summarized in Figure 6.

[Figure 6 about here]

The information cost of this organizational structure is the sum of the managers' information processing costs and of the field agents' observation costs. As before, the unit cost of observing evidence from the environment is assumed to be constant. The field agent's information cost (ic_i) is the product of the number of observations, o_i, and the unit cost of an observation, c. Thus, $ic_i = c \cdot o_i$. For $(n - v)$ field agents, the sum of observation costs is $(\sum c \cdot o_i,\ i = 1,...,(n - v))$. In this structure with 3-level hierarchies, the managers' information processing cost will be estimated as the sum of the information cost of the top manager and of the division managers. Each division manager needs to analyze and compare $(n - v)/v$ reports from each division's field agents. Thus the information processing cost of each division manager is $2^{(n - v)/v}$. The sum of the information cost of all division managers is $\sum 2^{(n - v)/v} = v(2)^{(n - v)/v}$. The top manager receives only v number of reports from the division managers. His information cost is 3^v. The managers' information processing cost would be $(v(2)^{(n - v)/v} + 3^v)$. Then the total information cost of this structure is $(c\sum o_i + v(2)^{(n - v)/v} + 3^v,\ i=1,...,(n - v),\ v < n)$.

This information cost will vary with the number of divisions. If the top manager wants to decrease his own information processing costs, he will reduce the number of divisions so that each division manager needs to analyze more reports and to pay more of the information cost. If the field agent observes the same k number of data from each jurisdiction and $c = 1$, then the total information cost of this structure would be $(k(n - v)$

$+ v(2)^{(n-v)/v} + 3^v, v < n)$.

This structure emphasizes information efficiency, instead of information reliability since it is increased by the specialization of the jurisdiction of a field agent. Information efficiency is based on the number of observations, N, which this organization generates. It is ($N = \sum o_i$, $i = 1,...,(n - v)$) when o_i is the number of observations of a_i. Since event predictability is proportional to a function of information efficiency and information reliability, such as EP $\propto$ N^{AN}. EP of this structure is proportional to a certain point on the interval $[\sum o_i, (\sum o_i)^{n-v}]$, $i = 1,...,(n - v)$. If all the field agents generate the same k data, then the interval would be $[(n - v)k, ((n - v)k)^{n-v}]$.

The advantages of this tall one-to-one structure are: (1) this structure would greatly reduce the burdens of the top manager to analyze and compare many reports by introducing middle-level managers whose task is to analyze the reports from the field agents, and transmit the condensed information to the top manager, while keeping the total number of his subordinates fixed; (2) as in flat one-to-one structure, information gathering can be more efficiently performed if the environment is decomposed into a certain number of separated jurisdictions; and (3) this structure provides more evaluation procedures which make the organizational report more accurate.

There is a conventional wisdom that the quality of information finally received by the top manager will probably be very different from the original reports of the field agents (Downs 1967). Wilensky (1967) postulated three structural conditions which increase the possibility of information distortion: (1) *hierarchy*, which restricts free information flows; (2) *specialization*, which reduces horizontal communications between the field agents; and (3) *centralization*, by which the top manager is too far removed from the actual observations. Wilensky (1967) argued: "The greater the number of ranks and the greater the number of organizational units involved in a decision process, the more the distorting influence of rank and jurisdiction and, consequently, the greater the chance of an intelligence failure" (p.57). However, this research indicates that information distortion can be removed by providing appropriate feedback.

The top manager of this tall one-to-one structure has moderately deterministic role in information processing because he shares the function of information aggregation with the division managers but he is the only one who can have information about the whole environment.

4.5. Tall one-to-many structure

A tall one-to-many structure consists of one top manager, *tm*, several division managers, dm_j, $j = 1,...,v$, $v < n$, and a number of field agents, a_i, $i = 1,...,(n - v)$. Each division has $(n - v)/v$ field agents. In each division all field agents have the same jurisdiction. Hence all a_i in a division observe the same portion of all E_i, that is, $e_i = (e_1,...,e_{n-v})$, $e_i \in E_i$, $e_i \in E$, $e = e_i = e_j$, $i \neq j$.

Field agent a_i generates information based on his observations of the common jurisdiction. Information generation by the field agents is similar with that in the flat one-to-many structure. The jurisdiction would be scrutinized from $(n - v)$ different perspectives. Even though all observe the same jurisdiction, each makes an estimate which might be different because each field agent has his own method of analysis. As a Bayesian player, the field agent has his own prior belief on the probability of event A, and he can continuously update it through feedback processes. He gathers a certain amount of information from the environment and makes a likelihood function. Then he constructs his posterior probability distribution function of event A as $p_i(A) = f(g_i(A), l_i(e))$. Based on his posterior probability, the field agent would report r_i to the division manager.

[Figure 7 about here]

Since all the field agents share a common jurisdiction, all reports are based on the same observations with different estimation methods. Thus if $r_i(A)$ is the same as $r_j(A)$, information is more reliable since there is an agreement between the two different estimations. $\sum r_i(A)$ would be the set of independent evaluations on the event A. In this structure, each field agent observes o number of data, $o = o_i = o_j$, $i \neq j$, from the environment e and the total information generation would be the same as o because of duplication effect. If a_i gathers k sample data from e, the total number of observations in this structure would be k since all field agents get the same sample data, but each a_i may interpret the data differently. Thus $\sum r_i$ is more affected by the field agents' subjective beliefs.

Each division manager receives $(n - v)/v$ reports from the field agents in his division. The role of the division manager is to compare and analyze the reports based on his own perspective and to transmit the divisional report to the top manager. The reports $r_i = f(g_i(A), l_i(e))$ would be re-evaluated from the view point of the division manager. dm receives $\sum r_i = \sum f(g_i(A), l_i(e))$ and assigns $w_i = f(w_i^{t-1}, w_j^{t-1}, r_i, r_j)$, $i \neq j$.

Each division manager aggregates only the reports from his own subordinates. By combining the reports and his own aggregation rule, the division manager aggregates the reports, $\mu_{dm} = \Sigma w_i r_i$, $i = 1,\ldots,(n - v)/v$. Then the division manager makes the divisional report on event A, based on his prior and this likelihood which is based on the common jurisdiction. The process of making the divisional report is: $\Sigma f(g_i(A), l_i(e)) \rightarrow \mu_{dm}$ with $g_{dm}(A) \rightarrow dr_j = f(g_{dm}(A), \mu_{dm}) = f(g_{dm}(A), l_{dm}(e))$. At this stage, the probabilities based on the different estimation methods can be combined into the probabilities based on the divisional aggregations: $[0, 1]^{(n - v)} \rightarrow [0, 1]^v$.

The top manager receives the reports from only the division managers. Since there are indirect reporting routes between the field agents and the top manager, the top manager can get access only to filtered information. But this reduces the top manager's information processing cost since $v < n$. When the top manager applies the relative weight rule, he needs to allocate the weights only to the divisions. Thus it might be easy to update the relative weights at each time. tm receives $\Sigma dr_j = \Sigma f(g_{dm}(A), \mu_{dm}) = \Sigma f(g_{dm}(A), l_{dm}(e))$. By using the reports from the division managers and his aggregation method, the top manager constructs his likelihood, that is, $\mu_{tm} = \Sigma w_j dr_j$, $j = 1,\ldots,v$. Then the top manager makes the organizational report on event A, based on his prior belief and this likelihood. The process of making the organizational report is: $\Sigma f(g_i(A), l_i(e)) \rightarrow \Sigma dr_j = f(g_{dm}(A), l_{dm}(e)) \rightarrow \mu_{tm}$ with $g_{tm}(A) \rightarrow r_{tm} = f(g_{tm}(A), \mu_{tm}) = f(g_{tm}(A), l_{tm}(e))$. At this point, the probabilities can be combined into the single probability: $[0, 1]^{(n - v)} \rightarrow [0, 1]^v \rightarrow [0, 1]$.

Feedback in this flat one-to-many structure functions as the way to reinforce the

Bayesian incentive compatible mechanism, and as the process to adjust the subjective perspectives of the field agents and the top manager on the event. After observing the state of the event, the top manager would update the relative weights on the division managers. Based on the feedback from the state of the event and from the top manager, the division managers would revise the relative weights on the field agents. By the feedback from the division manager and the state of the event, the field agents would update their prior beliefs and information estimation methods. The information processing in tall one-to-many structure would be summarized in Figure 8.

[Figure 8 about here]

The information cost of this organizational structure is the sum of the managers' information processing costs and of the field agents' observation costs. As before, the unit cost of observing evidence from the environment is assumed to be constant. The field agent's information cost (ic_i) is the product of the number of observations, o, which is the same for all a_i, and the unit cost of an observation, c. Even though all field agents observe the same data from the duplicated jurisdiction, and so each needs to analyze them independently, each needs to pay an information cost. Thus, $ic_i = ic = c \cdot o$. For $(n - v)$ field agents, the sum of observation costs is $(n - v) \cdot c \cdot o$. The managers' information processing cost will be the sum of the information cost of the division managers and the top manager. Each division manager needs to analyze and compare $(n - v)/v$ reports from the field agents. Thus the information cost of all division managers is $\Sigma 2^{(n - v)/v} = v(2)^{(n - v)/v}$. The top manager receives v number of reports from the division managers. His information cost will be 3^v. The total information cost of this structure is $((n - v)c \cdot o + v(2)^{(n - v)/v} + 3^v, v < n)$. This information cost will vary by the number of divisions. If all field agents observe the same k number of data, and the unit cost of observation is 1, then the total information cost of this structure is $((n - v)k + v(2)^{(n - v)/v} + 3^v, v < n)$.

Event predictability is proportional to the function of both information efficiency and information reliability. This structure emphasizes information reliability since it is increased by the duplication of the jurisdiction for all field agents and since this structure provides the three steps to estimate the event with the same ***e***. Information reliability is based on the number of similar reports in an organization. The more consensus on the state of the event the organization achieves, the more reliable the prediction is. Event predictability, EP, of this structure is proportional to N^{AN}, where N is the number of information generations and AN is the number of major agreement on the estimation. Thus EP is proportional to a certain point on the interval $[o, o^{(n - v)}]$. For comparability, if all the field agents generate k data, then the interval would be $[k, k^{(n - v)}]$.

This tall one-to-many structure, by using the common jurisdiction, seeks to benefit from the diverse views and judgments of field agents in predicting event *A*. The advantages of this structure are: (1) as in flat one-to-many structure, the reports from the field agents would be more reliable; (2) the field agents as well as the managers are able to have a broader perspective on the environment and event *A*, and it offers the field agents greater scope and responsibility in their prediction; and (3) as in tall one-to-one structure, by introducing middle-level managers the top manager can save his information processing cost, and the means for more evaluation is provided.

The top manager has a much less deterministic role in information processing because he shares the information aggregation function with the division managers as well as the field agents.

4.6. Comparative analysis of organizational structures

The previous sections have studied information processing in different organizational structures with the fixed n number of subordinates. This section summarizes the results by demonstrating that different organizational structures transmit different information to the top manager and by demonstrating, with regard to information cost and event predictability, what kind of organizational structure is more attractive to a top manager who designs an organization.

Proposition 1: Each organizational structure can transmit different information to the top manager, with the same number n of subordinates.

Proof: Organizational structure determines the way to aggregate reports into a collective one as explained in the previous sections. Since different organizational structures operate different aggregation methods, different organizational structures process different information to the top manager. The following table shows how different reports are given to the top manager.

	tm receives:
Flat one-to-one structure	(1) $\Sigma r_i = \Sigma f(g_i(A), l_i(E_i)),\ i = 1,\ldots,n.$
Flat one-to-many structure	(2) $\Sigma r_i = \Sigma f(g_i(A), l_i(e)),\ i = 1,\ldots,n.$
Tall one-to-one structure	(3) $\Sigma dr_j = \Sigma f(g_{dm}(A), l_{dm}(DE_j)),\ j = 1,\ldots,v.$
Tall one-to-many structure	(4) $\Sigma dr_j = \Sigma f(g_{dm}(A), l_{dm}(e)),\ j = 1,\ldots,v.$

(1) $\neq$ (2) $\neq$ (3) $\neq$ (4).
QED.

Even with the same n number of subordinates and the same environment E, different organizational structures generate different reports. The goal of a top manager, or an organizational designer who designs an organization, is to minimize information cost and to maximize event predictability. If the top manager decides that information cost is more critical than event predictability, he would choose the organizational structure which can minimize information cost regardless of event predictability. The following proposition shows what kind of organizational structure a manager needs so that he pays less information cost with the same n number of subordinates. As defined in Chapter 3.3, the information cost of an organization is the sum of the field agents' observation costs and of the managers' information processing costs. That is, IC = $\sum c \cdot o_i + \sum L_m^{N(r)}$. Let us assume that all the field agents generate the same k number of observations and the unit observation cost of the field agents is fixed as $c = 1$. The number of the field agents is greater than or equal to the number of the divisions in tall structures, $(n - v) \geq v$.

Proposition 2: The total information cost of tall structures is less than that of flat structures, if $n > 2$.

Proof: The information costs of organizational structures are:

	Information cost
Flat structures	$nk + 2^n$
Tall structures	$(n - v)k + v(2)^{(n - v)/v} + 3^v$.

where n, v, k are all integers, $n \geq 2v$, $v \geq 1$, $n > 2$, $k \geq 1$.

If both (1) $nk > (n - v)k$ and (2) $2^n > v(2)^{(n - v)/v} + 3^v$ are satisfied, then (3) $nk + 2^n > (n - v)k + v(2)^{(n - v)/v} + 3^v$ is also true.

(i) Since $n > v$ and $k \geq 1$, the inequality (1) is proved.

If (2) is verified with the minimum numbers of n and v, then the inequality is proved with all numbers. The minimum numbers satisfying $n > 2$, $v \geq 1$, and $n \geq 2v$ are $n = 3$ and $v = 1$.

With $n = 3$ and $v = 1$, $2^n = 2^3 = 8 > 7 = 2^2 + 3^1 = v(2)^{(n-v)/v} + 3^v$.
(ii) $2^n > v(2)^{(n-v)/v} + 3^v$, $\quad n > 2, n \geq 2v, v \geq 1$.

By (i) and (ii), the inequality (3) is proved.[4]
QED.

Proposition 2.1: The top manager's information processing cost is less in tall structures than in flat structures, if $n > 2$.

Proof: By the proof of Proposition 2, the managers' information processing cost of tall structures is less than that of flat structures.

$$2^n > v(2)^{(n-v)/v} + 3^v, \qquad n > 2, n \geq 2v, v \geq 1.$$

$$v(2)^{(n-v)/v} > 0.$$

	tm's information cost
Flat structures	2^n
Tall structures	3^v

Therefore, $2^n > 3^v$.
QED.

Tall structures are more attractive to the top manager who seeks to reduce information cost.[5] On the other hand, if the top manager emphasizes event predictability

[4] The result is also true even with unequal sizes of divisions in tall structures. The minimum numbers of n and v which make it possible to have the unequal sizes are $n = 5$ and $v = 2$ -- e.g., Division 1 has 2 field agents and Division 2 has 1 field agent. The information cost of this structure will be $3k + 2^2 + 2^1 + 3^2 = 3k + 15$, while that of the flat structure with $n = 5$ is $5k + 2^5 = 5k + 32$. The inequality (3) is proved since $5k + 32 > 3k + 15$, for $k \geq 1$.

[5] When criticizing transaction cost theory, Hammond (1991b) indicates that we need to differentiate the top manager's costs from those of his subordinates:

> It is more accurate to say that each structure reduces some actors' transaction costs while increasing the transaction costs of other actors. It follows that structural design hinges on the question of whether the chief executive's transaction costs are more important than those of the subordinates, or less important (p.63, fn.21).

more than information cost, he would choose the organizational structure which can maximize event predictability, with a given n number of subordinates, regardless of information cost. The general axioms of event predictability (EP) are that the more information efficiency, the more event predictability, and that the more information reliability, the more event predictability. Given the existence of the Bayesian incentive compatible mechanism, event predictability is proportional to the function of information efficiency and information reliability, as EP $\propto N^{AN}$, where N is the number of observations which an organization generates, and AN is the number of major agreement on the estimation. EP is proportional to a certain point on the interval of N^{AN}.

Proposition 3: The flat one-to-one structure generates greater event predictability than the other structural alternatives, given the existence of the relative weight rule as the Bayesian incentive compatible mechanism.

Proof: Let us assume that all the field agents observe the same k number of data, $k \geq 1$.

	Interval of N^{AN}
Flat one-to-one structure	$[nk,\ (nk)^n]$
Flat one-to-many structure	$[k,\ k^n]$
Tall one-to-one structure	$[(n - v)k,\ ((n - v)k)^{(n - v)}]$
Tall one-to-many structure	$[k,\ k^{(n - v)}]$

Using a minimax strategy, the top manager will choose the organizational structure which guarantees the maximum among the minimums of those intervals. Since $nk > (n - v)k > k$, $n > 2$, $k \geq 1$, $n > v \geq 1$, the flat one-to-one structure ensures the greatest information predictability among four structural alternatives.
QED.

The top manager would choose the tall structure in order to reduce information costs. For increasing event predictability, the top manager would design a flat one-to-one structure with using a Bayesian incentive mechanism. But the top manager would want to design an organizational structure which can minimize information cost and maximize event predictability simultaneously. Then the top manager's choice (*ch*) of an organizational structure is based on the function of both information cost, IC, and event predictability, EP:

$$ch = f(\text{IC}, \text{EP}) = \frac{\text{EP}}{\text{IC}}.$$

An organizational structure which ensures greater value in the choice function is better for the top manager. The following theorem demonstrates what kind of organizational structure is better choice for the top manager.

Theorem 2: The tall one-to-one structure is better than the other structural alternatives for the top manager, if $n > 4$.

Proof: Let us assume that all the field agents generate the same k observations, and the unit observation cost is constant as $c = 1$, and $n \geq 2v$, $v \geq 1$, $k \geq 1$. The top manager is supposed to design an organization based on the choice function.

	$ch = \frac{\text{EP}}{\text{IC}}$, and if EP $\propto$ the minimum of the interval of N^{AN}
Flat one-to-one structure	(1) $\frac{nk}{nk + 2^n}$
Flat one-to-many structure	(2) $\frac{k}{nk + 2^n}$
Tall one-to-one structure	(3) $\frac{(n - v)k}{(n - v)k + v2^{(n - v)/v} + 3^v}$
Tall one-to-many structure	(4) $\frac{k}{(n - v)k + v2^{(n - v)/v} + 3^v}$

If the value of an organizational structure in the choice function is greater than the others, it is the better for the top manager.

If the information cost is same, the greater the information predictability, the greater the value of the choice function.

(1) > (2), $nk > k, k \geq 1.$
(3) > (4), $(n - v)k > k, n \geq 2v, v \geq 1.$

Thus the choice is reduced to (1) and (3). Now let us suppose:

(i) --- (1) < (3).

If the inequality (i) is satisfied with the minimum numbers of n and v, then the result is also true with any numbers of n and v. The minimum numbers satisfying $n > 4$, $v \geq 1$, $n \geq 2v$ are $n = 5$ and $v = 1$. With these minimum numbers:

$$(1) = \frac{nk}{nk + 2^n} = \frac{5k}{5k + 2^5} = \frac{5k}{5k + 32}.$$

$$(3) = \frac{(n - v)k}{(n - v)k + v2^{(n - v)/v} + 3^v} = \frac{4k}{4k + 2^4 + 3} = \frac{4k}{4k + 19}.$$

Regardless of k, when $n > 4$, the inequality (i) is satisfied.[6] For example, if k = 1, (1) = .135 < .174 = (3). If k = 100, (1) = .940 < .955 = (3). Thus the inequality (i) is verified.
QED.

When considering both information cost and event predictability, the tall one-to-one structure is better than the other organizational structures, with $n > 4$.[7] At some

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6 Even though there is an unequal allocation of the field agents satisfying the conditions $n > 4$, $v \geq 1$, $n \geq 2v$, such as Division 1 has 2 field agents and Division 2 has only 1 field agent, the result is same. For instance, if n = 5, v = 2 and k = 1, (1) = .135 < .167 = (3). Also when $n > 4$, any kind of structural variation with $v \geq 1$ gives the greater value in the choice function than the structure with $v = 0$.

7 Several studies in the literature on structures are related to this result. Keren and Levhari (1979) suggested a model of pure hierarchy which oversees a given number of productive units. The model permits the calculation of an optimum formal structure of the hierarchy in terms of the span of control at different levels. When considering planning time, the total planning time in tall structure will be less than in flat structure so long as the number of productive units exceeds four. With the assumption that organization members are infallible in the absence of overload, Drenick (1986) demonstrated mathematically that flat structures may not achieve the objective of lightening the load on the top manager and tall structures are uniquely suited to the avoidance of overload. Keren and Levhari (1989) analyzed the aggregation and error in the multi-divisional form of organizational structure. The aggregation introduces error into decisions. They argued: "the degree of aggregation has to be selected so as to attain the optimal trade-off between the total variance of this choice process and administration costs" (p.217). Their model demonstrated that the span of control expands as one goes down the tiers of the hierarchy, and aggregation is the most radical in the lower levels of the hierarchy.

point in the growth of an organization it is necessary to formalize tall structure and to reduce information processing cost. While a flat one-to-one structure is able, by generating more information, to deal effectively with greater amounts of uncertainty than the tall one-to-one structure, there are greater information costs with this increased information generation capacity. With the great number of subordinates the disadvantage of information cost in the flat structure offsets the advantage of information predictability. However, if the top manager is willing to suffer the greater information processing costs, the flat one-to-one structure is more attractive since the top manager can allocate all the subordinates as the field agents, who do the actual observations, and the top manager can get all the reports.

Faced with an important event to estimate, the top manager would emphasize event predictability more. If it is necessary to analyze a huge amount of intelligence in order to predict the event, a flat one-to-one structure is preferable. When there is only a limited information, a flat one-to-many structure would be better since the information can be scrutinized from diverse perspectives. Table 3 summarizes the characteristics of each organizational structure in information processing.

The shape of the organizational structure -- not only the number of ranks but also the number of personnel at each level -- conditions the upward flow of information (Wilensky 1967, Hammond 1986, 1990b, 1991b). Structural arrangements in organizations determine the information processing patterns which, in turn, affect organizational outcomes. Organizational structures can also determine the specific role that the top manager will play in making organizational reports (Graber 1992).

Table 3: Characteristics of Organizational Structures

	Flat one-to-one structure	**Tall one-to-one structure**	**Flat one-to-many structure**	**Tall one-to-many structure**
consists of:	top manager, tm n field agents, a_i	top manager, tm v division, dm_j n field agents, a_i	top manager, tm n field agents, a_i	top manager, tm v division, dm_j n field agents, a_i
a_i's jurisdiction	E_i	E_i	e	e
a_i reports:	$r_i = f(g_i(A), l_i(E_i))$	$r_i = f(g_i(A), l_i(E_i))$	$r_i = f(g_i(A), l_i(e))$	$r_i = f(g_i(A), l_i(e))$
generates:	nk data	$(n - v)k$ data	k data	k data
dm_j receives:		$(n - v)/v$ reports		$(n - v)/v$ reports
tm receives:	n reports	v reports	n reports	v reports
tm receives:	$\Sigma r_i = \Sigma f(g_i(A), l_i(E_i)$	$\Sigma dr_j = \Sigma f(g_{dm}(A), \mu_{dm})$ $\mu_{dm} = \Sigma w_i r_i$	$\Sigma r_i = \Sigma f(g_i(A), l_i(e)$	$\Sigma dr_j = \Sigma f(g_{dm}(A), \mu_{dm})$ $\mu_{dm} = \Sigma w_i r_i$
dm_j uses:		$w_i = f(w_i^{t-1}, r_i)$		$w_i = f(w_i^{t-1}, r_i)$
tm uses:	$w_i = f(w_i^{t-1}, r_i)$	$w_j = f(w_j^{t-1}, dr_j)$	$w_i = f(w_i^{t-1}, r_i)$	$w_j = f(w_j^{t-1}, dr_j)$
For a_i	specialization & monopoly	specialization & monopoly	redundancy & competition	redundancy & competition
tm & a_i	direct interaction	indirect interaction	direct interaction	indirect interaction
tm has:	more deterministic role	moderate deterministic role	less deterministic role	much less deterministic role
Information cost	relatively high	relatively low	relatively high	relatively low
Event predictability	more efficient	more efficient	more reliable	more reliable
is generally:	more reliance on objective observations	more reliance on objective observations	more reliance on prior beliefs	more reliance on prior beliefs

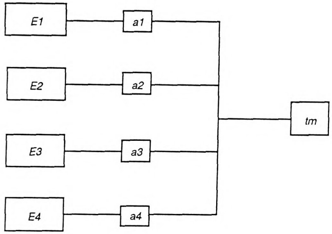

Figure 1: An example of flat one-to-one structure

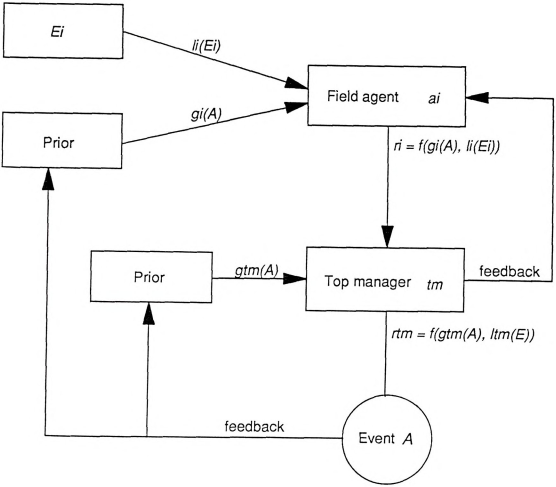

Figure 2: Information processing in flat one-to-one structure

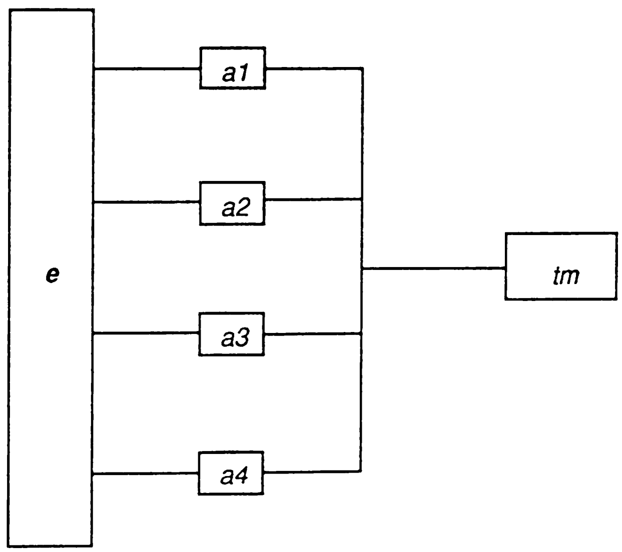

Figure 3: An example of flat one-to-many structure

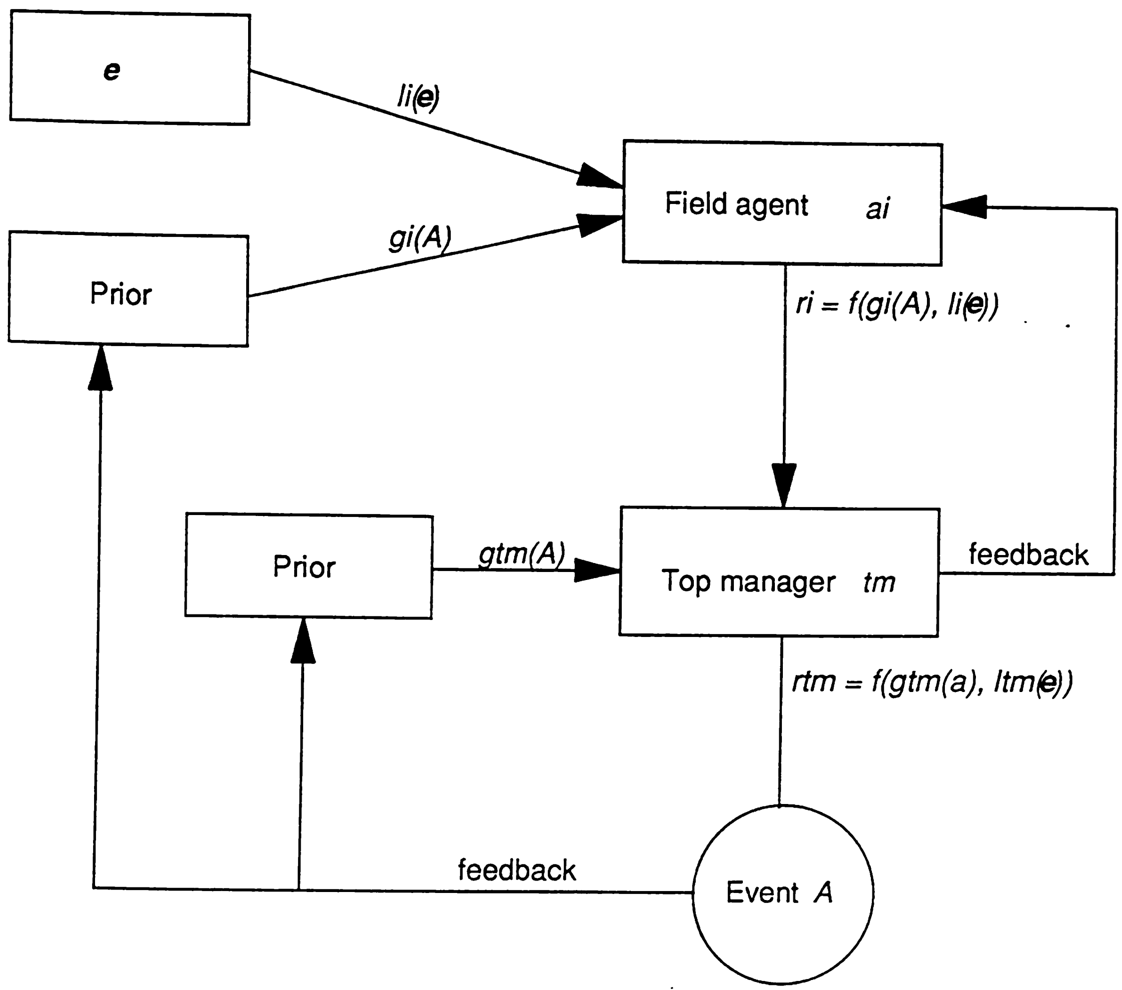

Figure 4: Information processing in flat one-to-many structure

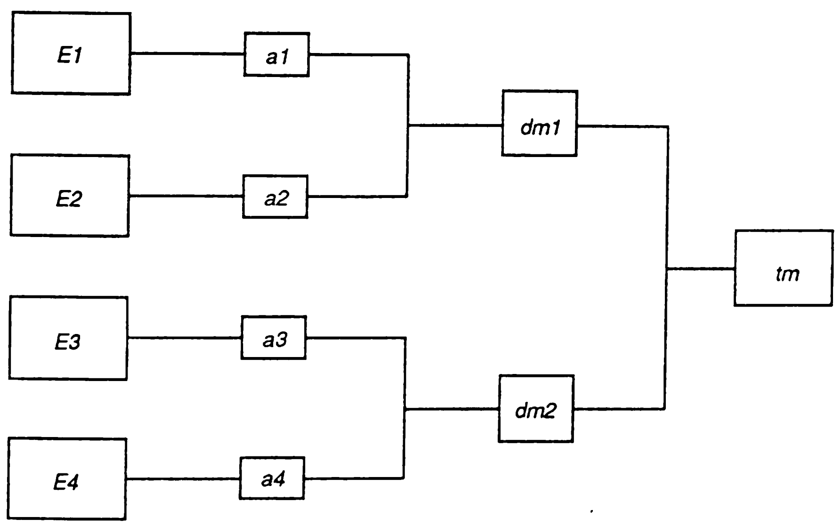

Figure 5: An example of tall one-to-one structure

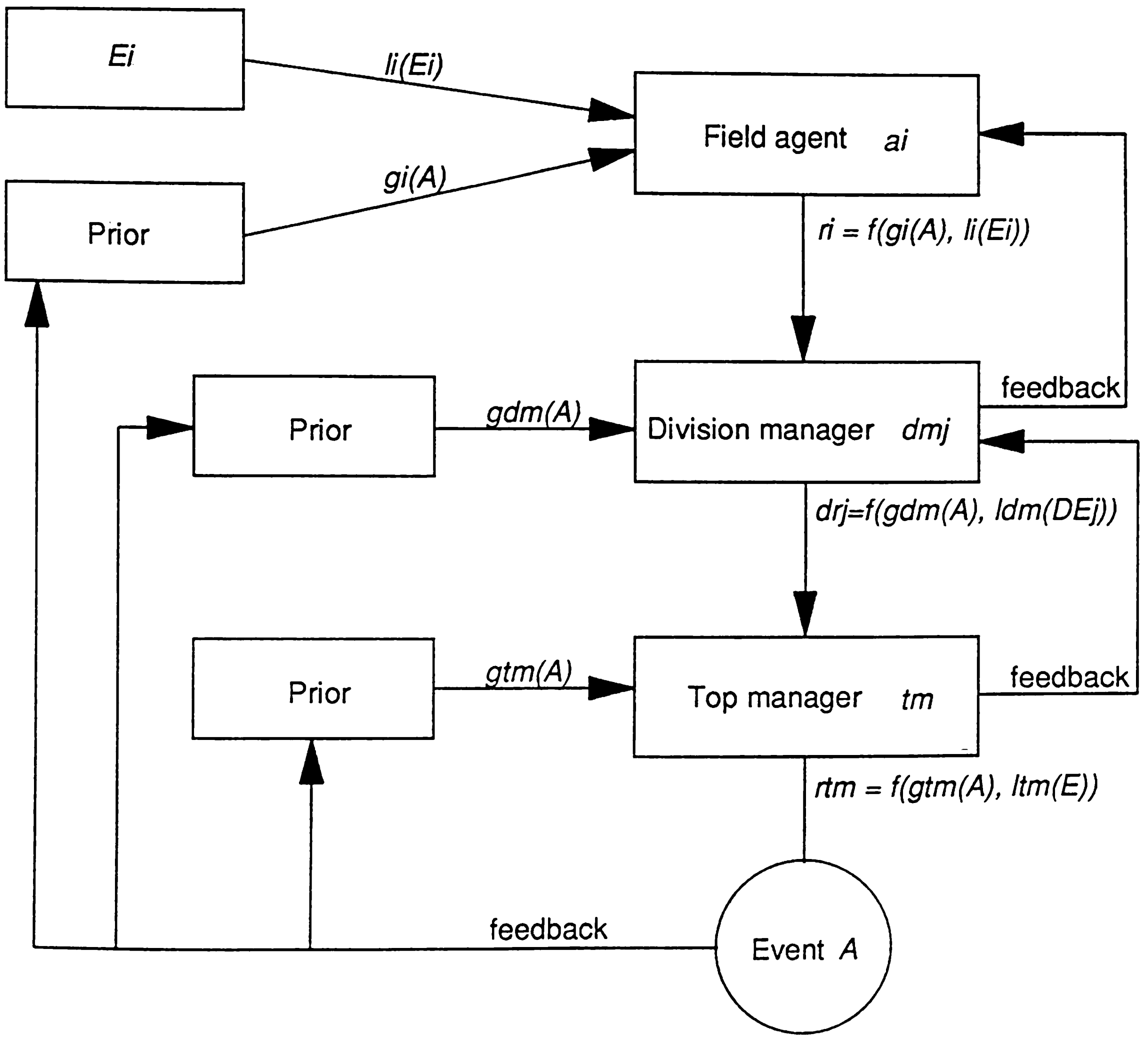

Figure 6: Information processing in tall one-to-one structure

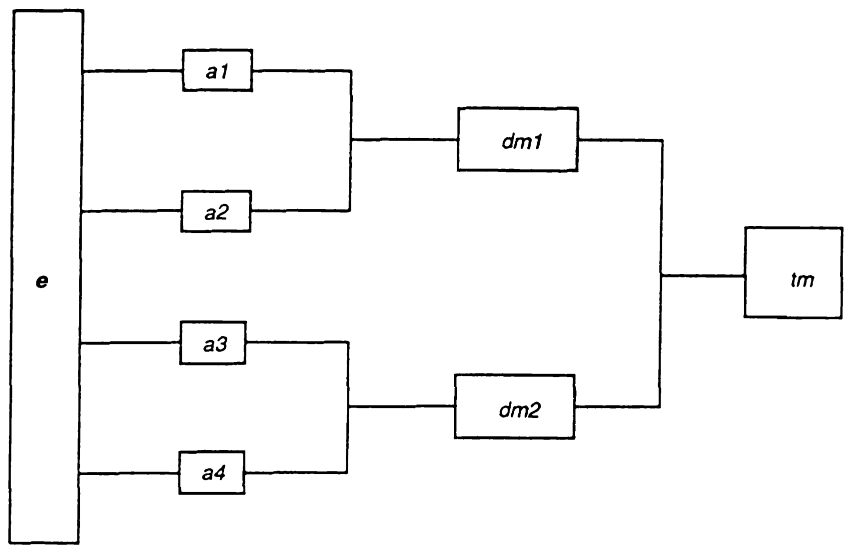

Figure 7: An example of tall one-to-many structure

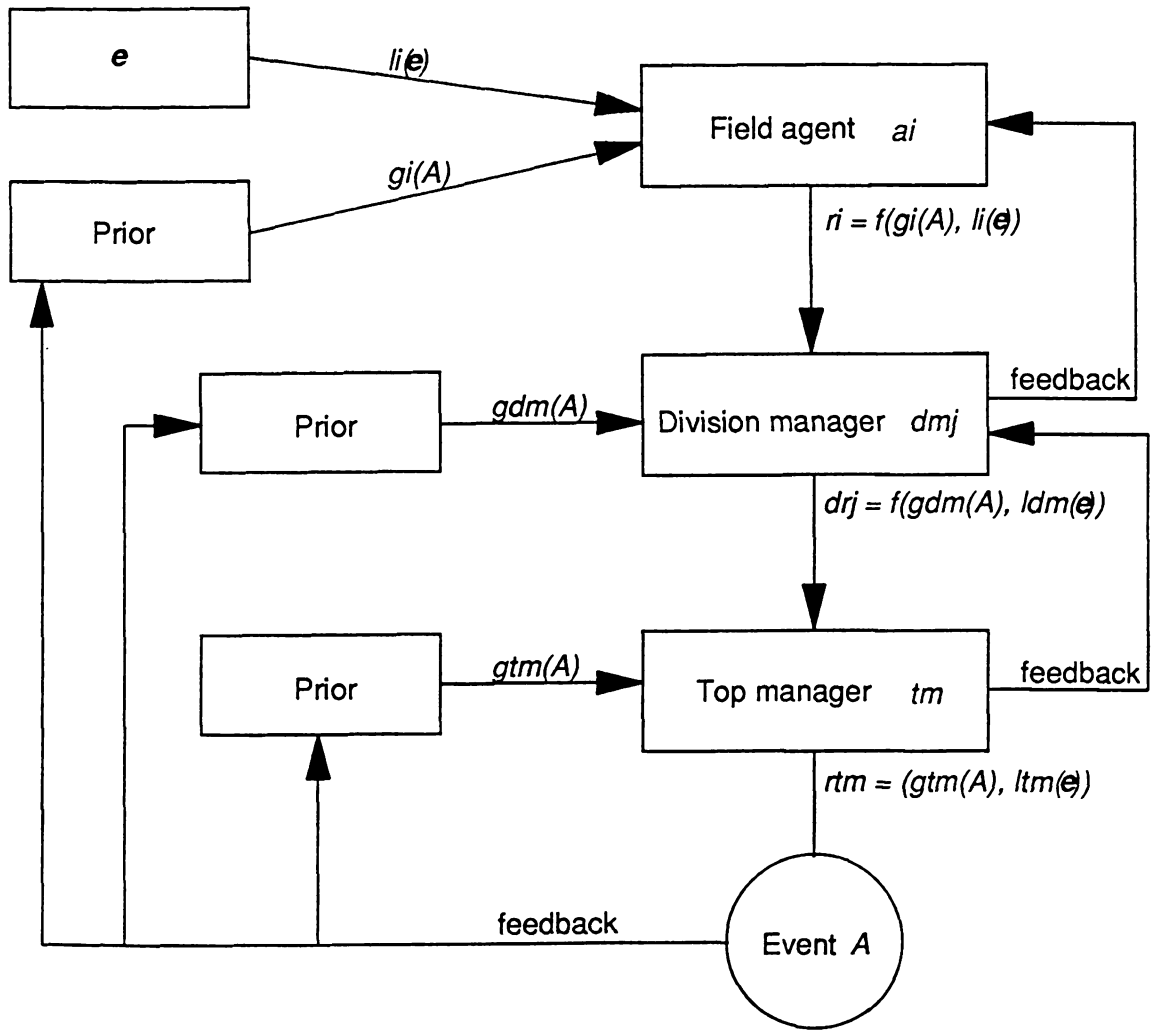

Figure 8: Information processing in tall one-to-many structure

5. An Example

The findings of this research will be illustrated through a numerical example. This example will demonstrate that different organizational structures transmit different information to the top manager, and that different organizational structures generate different information costs and event predictabilities. Let us consider a top manager, *tm*, who has six subordinates, a_i, $i = 1,...,6$. The responsibility of subordinates is to analyze information, and report the probability of event A in their jurisdictions. Event *A* is a binary variable that it will occur ($A = 1$) or not ($A = 0$). The probability of occurrence of the event is denoted as θ, while that of non-occurrence as $(1 - \theta)$. Depending upon the reports from the subordinates, the top manager periodically makes predictions of the probability of the occurrence of event *A*. The top manager wants to know how each organizational structure will affect the reports given to him, and which will be most appropriate in information processing.

Four models will be discussed, each with seven members--the top manager and six subordinates organized in four different ways. The first one is a flat one-to-one structure in which *tm* receives 6 reports from the field agents, and each a_i has his own jurisdiction. The second model is a flat one-to-many structure in which *tm* receives 6 reports from the field agents who share a common jurisdiction. The third model is a tall one-to-one structure in which *tm* receives 2 reports from division managers, dm_1 and dm_2. Each division consists of a division manager and 2 field agents. Each field agent has his own jurisdiction. Finally, there is a tall one-to-many structure in which *tm* receives 2 reports from division managers. All field agents have a common jurisdiction.

Information processing in this example will follow the procedures developed in Chapters 3 and 4. All individuals in the organization are Bayesian players. Each subordinate is independent from the others, and each has his own method of analyzing the data. At each time, there is an information set which consists of 36 data each of which may indicate whether the event will occur or not. Each field agent can evaluate only 6 pieces of data. All have the beta probability distribution function, $\beta(a, b)$. The expected value of the probability of occurrence of the event, $E(\theta)$, in the beta distribution $\beta(a, b)$, is $a/(a+b)$. Observing evidence of the occurrence of event A is treated as adding 1 to a in $\beta(a, b)$, and observing evidence of the non-occurrence of event A as adding 1 to b in $\beta(a, b)$. Assume also that all individuals have a common prior probability, $\beta(1,1)$ that is, $E(\theta) = 1/2$, on event A, and that the managers will give an equal weight to each report at time t. Now at time t the information set is given to the organization. The following table of information set shows that each E_i, i =1,...,6, consists of 6 pieces of data, and e also consists of 6 pieces of data each of which belongs to each E_i.

Information set at t

		e
E_1	c j h g i	g
E_2	i c h e j	d
E_3	h g f a e	h
E_4	h f b h f	a
E_5	g h e i h	j
E_6	g c i j h	i

Since each evaluates data with his own criteria, even though several agents may observe the same evidence, their conclusions may be different. For example, when a_1 and a_2 observe a piece of data "f" from the environment, a_1 may estimate that it is evidence of the likely non-occurrence of event A at $t + 1$, while a_2 may treat it as an evidence of the likely occurrence of the event. The evaluation criteria of subordinates are suggested as follows. For example, when a_1 observes one of the elements {a, b, c, d, e, f} from E_i, he will interpret it as an evidence of the likely non-occurrence of event A at $t + 1$, and he will add 1 to b in $\beta(a, b)$. On the other hand, when he observes one of the elements {g, h, i, j} from E_i, he will interpret it as an evidence of the likely occurrence of event A at $t + 1$, and he will add 1 to a in $\beta(a, b)$.

For a_1,	{a, b, c, d, e, f} = 0;	{g, h, i, j} = 1.
For a_2,	{a, b, c, d, e, g} = 0;	{f, h, i, j} = 1.
For a_3,	{a, b, c, d} = 0;	{e, f, g, h, i, j} = 1.
For a_4,	{a, b, c, d, g} = 0;	{e, f, h, i, j} = 1.
For a_5,	{a, b, c, e, f} = 0;	{d, g, h, i, j} = 1.
For a_6,	{a, b, d, g} = 0;	{c, e, f, h, i, j} = 1.

Information processing in the flat one-to-one structure at t

The information set is divided into 6 subsets, E_i, $i = 1,...,6$. Each a_1 needs to analyze each E_i, and report r_i to *tm*. Each time, this structure observes all 36 cases.

(1) a_1 observes E_1 which consists of 6 pieces of data, and estimates them with his own criteria. E_1 = {c, j, h, g, i, g}. Among 6 observations, 5 cases indicate the occurrence

of event A at $t + 1$; only one shows the non-occurrence. Then a_1 constructs his likelihood function as $l_1(E_1) = \beta(5,1)$. Since a_1's prior probability $g_1(A)$ is $\beta(1, 1)$, a_1 's posterior probability on event A is $p_1(A) = g_1(A)l_1(E_1) = \beta(5+1, 1+1) = \beta(6, 2)$. Under the incentive mechanism, a_1 behaves sincerely and reports r_1 as same as $p_1(A)$. Thus a_1 reports a probability, $\beta(6, 2)$, to *tm* at t.

(2) a_2 observes 6 pieces of from E_2, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_2 formulates his posterior probability, and reports $r_2 = \beta(3+1, 3+1) = \beta(4, 4)$.

(3) a_3 observes 6 pieces of from E_3, and finds that 5 cases indicate the likely occurrence of the event at $t + 1$, while the other 1 indicates the likely non-occurrence of the event. Then a_3 formulates his posterior probability, and reports $r_3 = \beta(5+1, 1+1) = \beta(6, 2)$.

(4) a_4 observes 6 pieces of from E_4, and finds that 4 cases indicate the likely occurrence of the event at $t + 1$, while the other 2 indicate the likely non-occurrence of the event. Then a_4 formulates his posterior probability, and reports $r_4 = \beta(4+1, 2+1) = \beta(5, 3)$.

(5) a_5 observes 6 pieces of from E_5, and finds that 5 cases indicate the likely occurrence of the event at $t + 1$, while the other 1 indicates the likely non-occurrence of the event. Then a_5 formulates his posterior probability, and reports $r_5 = \beta(5+1, 1+1) = \beta(6, 2)$.

(6) a_6 observes 6 pieces of from E_6, and finds that 5 cases indicate the likely

occurrence of the event at $t + 1$, while the other 1 indicates the likely non-occurrence of the event. Then a_6 formulates his posterior probability, and reports $r_6 = \beta(5+1, 1+1) = \beta(6, 2)$.

(7) tm receives r_i, $i = 1,...,6$, and aggregates them using the relative weight rule. At time t, tm will use an equal weight, $w_i = 1/6$. Then tm formulates his likelihood function by aggregating the reports. $\mu_{tm} = \sum w_i r_i$, $i = 1,...,6$.

$$\mu_{tm} = 1/6[\beta(6, 2) + \beta(4, 4) + \beta(6, 2) + \beta(5, 3) + \beta(6, 2) + \beta(6, 2)] = \beta(33, 15).$$

Since tm's prior is also $\beta(1, 1)$, $r_{tm} = \beta(33+1, 15+1) = \beta(34, 16)$. Thus the top manager will predict that the probability of event A at $t + 1$ is $34/50 = .68$.

<u>Information processing in the flat one-to-many structure at t</u>

All subordinates need to observe a common jurisdiction, which consists of 6 cases, $\boldsymbol{e}$ = {g, d, h, c, j, i}. The jurisdiction would be scrutinized from 6 different perspectives.

(1) a_1 observes $\boldsymbol{e}$, and estimates each evidence with his own criteria. Among 6 pieces of data, 4 cases indicate the occurrence of event A at $t + 1$. a_1 constructs his likelihood function as $l_1(\boldsymbol{e}) = \beta(4, 2)$. Since a_1's prior probability is assumed to be $\beta(1, 1)$, a_1's posterior probability on event A is $p_1(A) = \beta(4+1, 2+1) = \beta(5, 3)$. Under the incentive mechanism, a_1 reports $r_1 = p_1(A)$. Thus a_1 reports $r_1 = \beta(5, 3)$ to tm at t.

(2) a_2 observes the jurisdiction, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_2 formulates his posterior probability, and reports $r_2 = \beta(3+1, 3+1) = \beta(4, 4)$.

(3) a_3 observes the jurisdiction, and finds that 4 cases indicate the likely occurrence

of the event at $t + 1$, while the other 2 indicate the likely non-occurrence of the event. Then a_3 formulates his posterior probability, and reports $r_3 = \beta(4+1, 2+1) = \beta(5, 3)$.

(4) a_4 observes the jurisdiction, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_4 formulates his posterior probability, and reports $r_4 = \beta(3+1, 3+1) = \beta(4, 4)$.

(5) a_5 observes the jurisdiction, and finds that 5 cases indicate the likely occurrence of the event at $t + 1$, while the other 1 indicates the likely non-occurrence of the event. Then a_5 formulates his posterior probability, and reports $r_5 = \beta(5+1, 1+1) = \beta(6, 2)$.

(6) a_6 observes the jurisdiction, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_6 formulates his posterior probability, and reports $r_6 = \beta(3+1, 3+1) = \beta(4, 4)$.

(7) *tm* receives 6 reports, and aggregates them into his likelihood function with using an equal weight 1/6:

$$\mu_{tm} = 1/6[\beta(5, 3) + \beta(4, 4) + \beta(5, 3) + \beta(4, 4) + \beta(6, 2) + \beta(4, 4)] = \beta(28, 20).$$

With his prior probability $\beta(1, 1)$, he formulates $r_{tm} = \beta(28+1, 20+1) = \beta(29, 21)$. Thus the top manager predicts that the probability of event A at $t + 1$ is .58.

Information processing in the tall one-to-one structure at *t*

There are 2 divisions each of which has 2 field agents. dm_1, acted by a_3, receives the reports from a_1 and a_2, and dm_2, performed by a_6, receives 2 reports from a_4 and a_5.

This structure observes 24 cases from E_1, E_2, E_4, and E_5.[1]

(1) a_1 observes E_1, and estimates each case with using his own method. Among 6 observations, 5 cases support the occurrence of event A. a_1 constructs his likelihood function as $l_1(E_1) = \beta(5, 1)$. Since a_1's prior probability on the event is $\beta(1, 1)$, a_1's posterior probability on event A is $p_1(A) = \beta(5+1, 1+1) = \beta(6, 2)$. a_1 reports $r_1 = \beta(6, 2)$ to dm_1.

(2) a_2 observes 6 pieces of from E_2, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_2 formulates his posterior probability, and reports $r_2 = \beta(3+1, 3+1) = \beta(4, 4)$.

(3) a_4 observes 6 pieces of from E_4, and finds that 4 cases indicate the likely occurrence of the event at $t + 1$, while the other 2 indicate the likely non-occurrence of the event. Then a_4 formulates his posterior probability, and reports $r_4 = \beta(4+1, 2+1) = \beta(5, 3)$.

(4) a_5 observes 6 pieces of from E_5, and finds that 5 cases indicate the likely occurrence of the event at $t + 1$, while the other 1 indicates the likely non-occurrence of the event. Then a_5 formulates his posterior probability, and reports $r_5 = \beta(5+1, 1+1) = \beta(6, 2)$.

(5) dm_1 receives r_1 and r_2, and aggregates them using the relative weight rule. At t,

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[1] The top manager can also consider the different combinations of data. That is, he can assign to a_1 4 pieces of data from E_1 and 2 from E_2, and to a_2 2 pieces of data from E_2 and 4 from E_3, and so on. Then it can cover all E_i with observing 4 pieces of data from each E_i ($4 \times 6 = 24$). But it is nothing but the different assignment of jurisdictions, which also generates different reports to the top manager.

dm_1 will give an equal weight 1/2 to each report:

$$\mu_{dm1} = 1/2[\beta(6, 2) + \beta(4, 4)] = \beta(10, 6).$$

With his prior probability function $\beta(1, 1)$, dm_1 constructs his posterior probability, $p_{dm1}(A) = \beta(10+1, 6+1) = \beta(11, 7)$. Under the incentive mechanism dm_1 behaves sincerely, and thus he reports $r_{dm1} = \beta(11, 7)$ to *tm*.

(6) dm_2 receives r_4 and r_5, and formulates his likelihood function using the relative weight rule:

$$\mu_{dm2} = 1/2[\beta(5, 3) + \beta(6, 2)] = \beta(11, 5).$$

With his prior probability, dm_2 reports $r_{dm2} = \beta(11+1, 5+1) = \beta(12, 6)$ to *tm*.

(7) *tm* receives r_{dm1} and r_{dm2}, and aggregates them into his likelihood function using an equal weight 1/2:

$$\mu_{tm} = 1/2[\beta(11, 7) + \beta(12, 6)] = \beta(23, 13).$$

With his prior probability $\beta(1, 1)$, he will formulate $r_{tm} = \beta(23+1, 13+1) = \beta(24, 14)$. The top manager will predict that the probability of the occurrence of the event A is .632.

<u>Information processing in the tall one-to-many structure at *t*</u>

There are 2 divisions. dm_1, acted by a_3, receives r_1 and r_2, and dm_2, performed by a_6, receives the reports from a_4 and a_5. The division managers transmit the reports to *tm*. All field agents--a_1, a_2, a_3, and a_4--have the common jurisdiction e.

(1) a_1 observes e, and estimates each case with using his own criterion. Among 6 observations, 4 cases indicate the occurrence of event A at $t + 1$. a_1 constructs his likelihood function as $l_1(e) = \beta(4, 2)$. a_1's posterior probability on event A is $p_1(A) =$

$\beta(4+1, 2+1) = \beta(5, 3)$. Under the incentive mechanism, a_1 reports $r_1 = p_1(A)$. Thus a_1 reports $r_1 = \beta(5, 3)$ to dm_1.

(2) a_2 observes the jurisdiction, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_2 formulates his posterior probability, and reports $r_2 = \beta(3+1, 3+1) = \beta(4, 4)$.

(3) a_4 observes the jurisdiction, and finds that 3 cases indicate the likely occurrence of the event at $t + 1$, while the other 3 indicate the likely non-occurrence of the event. Then a_4 formulates his posterior probability, and reports $r_4 = \beta(3+1, 3+1) = \beta(4, 4)$.

(4) a_5 observes the jurisdiction, and finds that 5 cases indicate the likely occurrence of the event at $t + 1$, while the other 1 indicates the likely non-occurrence of the event. Then a_5 formulates his posterior probability, and reports $r_5 = \beta(5+1, 1+1) = \beta(6, 2)$.

(5) dm_1 receives r_1 and r_2. Using the aggregation rule, he will formulate his likelihood function:

$$\mu_{dm1} = 1/2[\beta(5, 3) + \beta(4, 4)] = \beta(9, 7).$$

Using his prior probability and likelihood function, dm_1 constructs his posterior probability as $p_{dm1}(A) = \beta(9+1, 7+1) = \beta(10, 8)$. Under the incentive mechanism, he will report $r_{dm1} = \beta(10, 8)$.

(6) dm_2 has r_4 and r_5, and aggregates them with an equal weight 1/2:

$$\mu_{dm2} = 1/2[\beta(4, 4) + \beta(6, 2)] = \beta(10, 6).$$

Thus dm_2 will report $r_{dm2} = \beta(10+1, 6+1) = \beta(11, 7)$ to tm.

(7) tm receives 2 reports, r_{dm1} and r_{dm2}, and formulates his likelihood function with an equal weight:

$\mu_{tm} = 1/2[\beta(10, 8) + \beta(11, 7)] = \beta(21, 15)$.

tm's posterior probability will be $r_{tm} = \beta(21+1, 15+1) = \beta(22, 16)$. The top manager predicts that the probability of event *A* at $t + 1$ is .579.

Weight updating at $t + 1$

At $t + 1$, assume that event *A* has occurred, that is, $A = 1$. Then the managers need to update the relative weights. The relative weight at $t + 1$ will be calculated by the report at *t* and the weight at *t*. The updating rule when $A = 1$ is:

$$w_i^{t+1} = \frac{w_i^t r_i^t}{\sum w_i^t r_i^t} \quad .$$

(1) In the flat one-to-one structure, the top manager needs to update 6 relative weights based on the previous equal weight and the reports at *t* since he receives 6 reports at each time. $\sum w_i r_i = 33/48$.

For a_1, w_1 at $t + 1$ will be 6/33. This updated weight is greater than 1/6.

For a_2, w_2 at $t + 1$ will be 4/33. This updated weight is less than 1/6.

For a_3, w_3 at $t + 1$ will be 6/33. This updated weight is greater than 1/6.

For a_4, w_4 at $t + 1$ will be 5/33. This updated weight is less than 1/6.

For a_5, w_5 at $t + 1$ will be 6/33. This updated weight is greater than 1/6.

For a_6, w_6 at $t + 1$ will be 6/33. This updated weight is greater than 1/6.

The sum of the updated relative weights is also 1. When the top manager aggregates the reports at $t + 1$, he would use the updated weights.

(2) In the flat one-to-many structure, the top manager needs to update 6 relative weights based on the previous equal weight and the reports at *t* since he receives 6 reports

at each time. $\sum w_i r_i = 28/48$.

For a_1, w_1 at $t + 1$ will be 5/28. This updated weight is greater than 1/6.

For a_2, w_2 at $t + 1$ will be 4/28. This updated weight is less than 1/6.

For a_3, w_3 at $t + 1$ will be 5/28. This updated weight is greater than 1/6.

For a_4, w_4 at $t + 1$ will be 4/28. This updated weight is less than 1/6.

For a_5, w_5 at $t + 1$ will be 6/28. This updated weight is greater than 1/6.

For a_6, w_6 at $t + 1$ will be 4/28. This updated weight is less than 1/6.

The sum of the weights is 1. The top manager will use these updated weights to aggregate the probabilities at $t + 1$.

(3) In the tall one-to-one structure, both the top manager and the division managers need to update the relative weights. The top manager will update the relative weights of the division managers, and each division manager will revise the weights of the field agents. $\sum w_{dmi}^t r_{dmi}^t = 23/36$. The updating rule for r_{dm} when $A = 1$ is:

$$w_{dmi}^{t+1} = \frac{w_{dmi}^t r_{dmi}^t}{\sum w_{dmi}^t r_{dmi}^t}$$

For dm_1, w_{dm1} at $t + 1$ will be 11/23. This updated weight is less than 1/2.

For dm_2, w_{dm2} at $t + 1$ will be 12/23. This updated weight is greater than 1/2.

In Division 1, $\sum w_i^t r_i^t = 10/16$, $i = 1, 2$. In Division 2, $\sum w_i^t r_i^t = 11/16$, $i = 4, 5$. The updating rule for r_i when $A = 1$ is:

$$w_i^{t+1} = \frac{w_i^t r_i^t}{\sum w_i^t r_i^t} \quad .$$

For a_1, w_1 at $t + 1$ will be 6/10. This updated weight is greater than 1/2.

For a_2, w_2 at $t + 1$ will be 4/10. This updated weight is less than 1/2.

For a_4, w_4 at $t + 1$ will be 5/11. This updated weight is less than 1/2.

For a_5, w_5 at $t + 1$ will be 6/11. This updated weight is greater than 1/2.

The sum of the relative weights of division managers is 1. In each division, the sum of the relative weights of field agents is also 1. When aggregating the reports at $t + 1$, each manager will assign the revised relative weight to each report.

(4) In the tall one-to-many structure, both the top manager and the division managers need to update the relative weights as in the tall one-to-one structure. The top manager will update the relative weights of the division managers, and each division manager will revise the weights of the field agents in his division. $\sum w_{dmi}{}^t r_{dmi}{}^t = 21/36$. The updating rule for r_{dm} when $A = 1$ is:

$$w_{dmi}{}^{t+1} = \frac{w_{dmi}{}^t r_{dmi}{}^t}{\sum w_{dmi}{}^t r_{dmi}{}^t}$$

For dm_1, w_{dm1} at $t + 1$ will be 10/21. This updated weight is less than 1/2.

For dm_2, w_{dm2} at $t + 1$ will be 11/21. This updated weight is greater than 1/2.

In Division 1, $\sum w_i^t r_i^t = 9/16$, $i = 1, 2$. In Division 2, $\sum w_i^t r_i^t = 10/16$, $i = 4, 5$. The updating rule for r_i when $A = 1$ is:

$$w_i^{t+1} = \frac{w_i^t r_i^t}{\sum w_i^t r_i^t}$$

For a_1, w_1 at $t + 1$ will be 5/9. This updated weight is greater than 1/2.

For a_2, w_2 at $t + 1$ will be 4/9. This updated weight is less than 1/2.

For a_4, w_4 at $t + 1$ will be 4/10. This updated weight is less than 1/2.

For a_5, w_5 at $t + 1$ will be 6/10. This updated weight is greater than 1/2.

The sum of the relative weights of division managers is 1. In each division, the sum of the relative weights of field agents is also 1. When aggregating the reports at $t + 1$, each manager will assign the revised relative weight to each report. Each time, the managers need to revise the relative weights so that they can ensure honest reporting.

At time $t + 1$, a new information set will be given. The field agents in these four models will also observe the information set, and process the probabilities on the occurrence of event A at $t + 2$. Then the managers will aggregate the reports with using the revised relative weights, w_i^{t+1}. After observing the state of event A at $t + 2$, the managers will update the relative weights again. Through these procedures, prior beliefs and evaluation criteria will also be adjusted.

This example has demonstrated how different organizational structures affect the processing and aggregation of information in the organization. First, it shows that each different organizational structure transmits different reports to the top manager. Even though the subordinates in these four structures observe the same information set, and all individuals begin with the same prior probability, the reports given to the top managers are different, as are the predictions by the top managers. For example, the aggregated reports in the flat one-to-one structure is $\beta(33, 15)$, while that in the tall one-to-one structure is $\beta(23, 13)$. Also when the top manager in flat one-to-one structure predicts the probability of the occurrence of event A at $t + 1$ as .68, the top manager in the tall one-to-many structure calculates that probability as .579.

Second, each organizational structure observes a different number of cases. For instance, the flat one-to-one structure examines 36 cases, while the flat one-to-many structure generates only 6 observations.

Third, different organizational structures need to pay different information cost. The top manager's information cost (ic_{tm}) of flat structures is 2^6 but that of tall structures is 3^2. The information cost (IC) of flat structures is 100 (= 36 + 2^6), whereas that of tall structures is only 41 (= 24 + 2×2^2 + 3^2).

Finally, at $t + 1$, each organizational structure generates a different event predictability. Event predictability is estimated as the function of both information efficiency and information reliability. It is expected to be proportional to N^{AN}, when N is the number of observations, and AN is the number of major agreements on the probability. The interval of N^{AN} can be calculated. That of the flat one-to-one structure is [36, 36^6] since this structure examines all 36 pieces of data, and the possible maximum number of agreements is 6. That of the tall one-to-many structure is [6, 6^4] since this structure examines only 6 pieces of data, and the possible maximum number of agreements among the field agents is 4. From the reports at t, we can calculate the point estimate of N^{AN} in each structure. That of the flat one-to-one structure is 36^4 because 4 among 6 field agents agree on the probability of event A at $t + 1$, while that of tall one-to-many structure is 6^2 because 2 among 4 field agents agree on the probability of the event at $t + 1$. When assuming that event A has occurred at $t + 1$, event predictability can be calculated by the deviation between the prediction and the actual state of the event, that is, EP = $1 - |A - r_{tm}|$, $A = \{0, 1\}$. The event predictability of the flat one-to-one structure at this time is .68, while that of the flat one-to-many structure is .58. But EP will vary at each time when observing the actual state of the event. Thus when designing an organizational structure, the top manager needs to consider the interval of N^{AN} as an indicator of event predictability. The following table summarizes the results of this example.

	Flat one-to-one	**Flat one-to-many**	**Tall one-to-one**	**Tall one-to-many**
observes:	36	6	24	6 data
tm receives:	6	6	2	2 reports
μ_{tm}	β(33, 15)	β(28, 20)	β(23, 13)	β(21, 15)
r_{tm}	.68	.58	.632	.579
ic_{tm}	64	64	9	9
IC	100	100	41	41
Interval of N^{AN}	$[36, 36^6]$	$[6, 6^6]$	$[24, 24^4]$	$[6, 6^4]$
Point estimate of N^{AN} at t	36^4	6^3	24^2	6^2
EP, t+1, A=1	.68	.58	.632	.579

6. Organizational Structure and Environment

Theorem 2 in Chapter 4 concludes that the tall one-to-one structure is in general better than the other structural models, when assuming all factors except structure to be constant. This result does not consider the characteristics of the environment even though the organization gathers information from the environment. Now let us extend the discussions of organizational structures to the relation between the environment and organizational structure. The assumption is modified; all other factors except structure and environment are constant. This study views an organization as open, information processing system. Organizational information processing is affected by, and dependent upon, its environment. The purpose of this chapter is to relate the structural models developed in Chapter 4 with the characteristics of the environment.

Most scholars have used two variables and a 2 x 2 matrix to classify the environment. Thompson (1967) classified the environment as homogeneous-stable, homogeneous-shifting, heterogeneous-stable, and heterogeneous-shifting. Lawrence and Lorsch (1967) categorized it into low diversity and not dynamic, low diversity and highly dynamic, high diversity and not dynamic, and high diversity and highly dynamic. Duncan (1972) used simple-static, simple-dynamic, complex-static, and complex-dynamic. Let us keep, for purposes of argument, the view of this study that assumes an organization is an information processing system and the organizational environment is the source of information perceived by the organization. The field agents would gather and analyze information, and transmit the reports to the managers. Then finally the top manager aggregates the reports and makes organizational announcements. When the top manager designs an organizational structure, he will also consider the characteristics of the environment as well as those of organizational structures. He will emphasize different principles of information processing when facing different characteristics of the environment.

Following Thompson (1967), we can characterize the environment with two dimensions dealing with degree of information homogeneity and degree of information stability. First, the environment is characterized as (relatively) homogeneous or heterogeneous, indicating whether the information generated from the environment is similar to one another. Second, the environment is classified as stable or shifting, indicating whether the range of information variations is large. By using these two dimensions, the environment would be classified as homogeneous-stable, homogeneous-shifting, heterogeneous-stable, and heterogeneous-shifting.

With the homogeneous and stable environment, the organization can gather a certain amount of similar information with small variations. Since information is homogeneous, information reliability by achieving consensus in estimating information is considered more important than information efficiency by increasing the number of observations. For increasing information reliability, achieving consensus in estimating information is more important than increasing the number of observations. It is appropriate to assign a common jurisdiction to field agents since it seeks to benefit from the diverse perspectives of field agents in predicting the event. Since information is stable, the top manager himself does not need to review all reports, and then it is better for him to reduce his information costs by introducing middle-level managers. With this kind of environment, the top manager will give emphasis to increasing information reliability and reducing information cost. Thus the appropriate structure with this homogeneous and stable environment is a tall one-to-many structure that emphasizes information reliability and smaller information cost.

With the homogeneous and shifting environment, the organization can get a certain amount of similar information with large variations. Since information is homogeneous, the agreement on predicting the event is more important than the amount of information. Assigning a common jurisdiction is better for getting consensus from diverse viewpoints of field agents. Since the range of information variation is so large, the top manager wants to analyze all reports with no filtration, and get a more direct role in aggregating reports. Also for increasing event predictability, he will assign all subordinates as the field agents to observe the environment. With this kind of environment, he will give emphasis to increasing information reliability but have less concern for information costs. The appropriate structure with this homogeneous and shifting environment is a flat one-to-many structure that focuses on information reliability and the top manager's direct role in making the predictions.

With the heterogeneous and stable environment, the organization can gather a certain amount of different information with small variations. Since information is heterogeneous, increasing information efficiency by increasing the number of observations is considered more important than information reliability. For increasing information efficiency, the organization needs to assign separate jurisdictions, each corresponding to a relatively homogeneous segment of the environment. Thus information gathering can be more efficiently performed with specialization. Since information is stable, the top manager does not need to aggregate all reports with paying a great information cost. The top manager can reduce his information costs by introducing middle-level managers whose task is to transmit a condensed report. With this kind of environment, the top manager will want to increase information efficiency and reduce information cost. The appropriate structure with this heterogeneous and stable environment is a tall one-to-one structure that emphasizes information efficiency and less information cost.

With the heterogeneous and shifting environment, the organization can get a certain amount of different information with large variations. Since information is heterogeneous, the organization needs to decompose the environment into a certain number of separate jurisdictions, for analyzing more information with specialized perspectives. Since the range of information variation is large, the top manager wants to get access to the reports from the field agents without any filtration. For increasing event predictability, he will assign all subordinates as the field agents to observe the environment. With this kind of environment, he wants to increase information efficiency but less concerns on information cost. The appropriate structure with this heterogeneous and shifting environment is a flat one-to-one structure that emphasizes information efficiency and the top manager's deterministic role in the event prediction.

Different principles of information processing will be emphasized when facing different characteristics of the environment. With the stable environment, the tall structure is better than the flat structure since it can reduce information costs. With the shifting environment, the flat structure is better than the tall structure since it can increase event predictability. With the homogeneous environment, the one-to-many structure is better than the one-to-one structure since it can increase information reliability. With the heterogeneous environment, the one-to-one structure is better than the one-to-many structure since it can increase information efficiency.

These results enrich the discussions of organizational structure. When the environment is constant, the tall one-to-one structure is better than the others. When considering other characteristics of the environment, different structures will work better in different environments. The results are summarized in Table 4.

Table 4: Optimal Organizational Structure in Different Environments

	Stable	Shifting
Homogeneous	**Tall one-to-many structure**	**Flat one-to-many structure**
Heterogeneous	**Tall one-to-one structure**	**Flat one-to-one structure**

7. Conclusion

In this research I addressed three questions about organizational structure and information processing. The first research question was "How does organizational structure affect the information transmitted through it?" To answer it, I developed four kinds of organizational structures focusing on specialization and coordination: flat one-to-one, flat one-to-many, tall one-to-one, and tall one-to-many structures. Chapter 4 shows that different organizational structures generate different information for the top manager and that each organizational structure has its own unique advantages and disadvantages in information processing. The discussions are summarized in Proposition 1 and Table 3. Chapter 5 illustrates the findings of Chapter 4 through a numerical example.

The second question was "What kind of organizational structure will be most appropriate in information processing?" With regard to information cost and event predictability, four kinds of organizational structures were compared. Propositions 2 and 2.1 demonstrate that the information cost of tall structures is less than that of flat structures for the top manager as well as the whole organization. Proposition 3 indicates that the flat one-to-one structure generates greater information predictability than the other structural alternatives, given the existence of the relative weight rule. Based on Propositions 2, 2.1, and 3, Theorem 2 demonstrates that when considering both information cost and information predictability, the tall one-to-one structure is better than the other organizational structures, with $n > 4$. When considering the relation between organizational structure and environment, Chapter 6 shows that different principles of information processing will be emphasized when facing different characteristics of the environment, and different structures will work better in different environments.

The third question was "What kind of incentive mechanism can be used by the top manager to ensure that subordinates report information honestly in a particular kind of organizational structure?" Chapter 2 discusses information processing and aggregation, and develops the relative weight rule as a Bayesian incentive compatible mechanism. Theorem 1 demonstrates that under the assumptions that all individuals are Bayesian players, and that there exist feedback processes, the relative weight rule is a Bayesian incentive compatible mechanism. In the information processing game, the field agent will report honestly and the manager will use the relative weight rule appropriately under a Bayesian incentive compatible mechanism. With regard to this result, the issues of collusion, and risk preference will be discussed in the following sections.

Organizational politics may play an important role in organizational information processing. Within the information processing framework of this study, organizational politics means the management of relative influence on the organizational predictions of event A. The coalition among the subordinates is one of the most important players in the political arena (March and Simon 1958, Cyert and March 1963). Stevenson *et al.* (1985) define a coalition as "an interacting group of individuals, deliberately constructed, independent of the formal structure, lacking its own internal formal structure, consisting of mutually perceived membership, issue oriented, focused on a goal or goals external to the coalition, and requiring concerted member action" (p.261). Following this definition, a coalition in this study refers to a group of subordinates that work together to influence the organizational predictions by reporting an agreed probability.

Under the existence of the relative weight rule as a Bayesian incentive compatible mechanism, a coalition among the subordinates may not be developed for two reasons. First, a coalition cannot escape from the fundamental problem of team theory--free-riding (Alchian and Demsetz 1972, Marschak and Radner 1972). Under the coalition, each coalition member still needs to observe the jurisdiction, and to make the posterior probability. Then the coalition will reach an agreed probability through inner-bargaining processes. In this situation no one wants to pay his own observation costs for making the probability. Every member wants to just follow the other's report with no effort to evaluate the data. Thus every coalition member will become a free-rider. Second, the coalition cannot ensure the maximum relative weight but an average weight. Since the same report will be transmitted to the manager, each member can get only the average weight equally. From the standpoint of maximizing the relative weight, it is not a good strategy to join a coalition for sharing only an average weight. Thus when applying the relative weight in information aggregation, the manager might not be manipulated by a coalition among the subordinates.

The issue of risk preference may be important for understanding the individual behavior in information processing. Now let us analyze whether the degree of risk aversion may be relevant to the information processing game. Theorem 1 shows that the relative weight rule is a Bayesian incentive compatible mechanism. Under this incentive mechanism, the dominant strategy of the field agents is to report honestly. Individual risk preference is not considered in this game. But the degree of risk aversion may be irrelevant since the Bayesian incentive compatible mechanism requires all field agents to behave sincerely regardless of risk preference.

When all field agents are the relative weight maximizers, the risk-avoider (a_1) may care more about keeping his current weight, while the risk-taker (a_2) may care more about increasing his weight in the future. The great merit of the relative weight rule is that the relative weight of a field agent a_i cannot be manipulated by himself but decided by *both* r_i and $\sum r_j$, $j \neq i$. For the risk-avoider, keeping his current weight is dependent upon his report and the others' reports. Since the state of event A is under uncertainty, a_1 may report strategically $r_1 = .5$ when $p_1(A) = .6$ or $p_1(A) = .4$. When a_1 reports $r_1 = .5$ but $p_1(A) = .6$, and the event occurs, if the others report $r_j > .5$, w_1 will be dramatically decreased. When a_1 reports $r_1 = .5$ but $p_1(A) = .4$, and the event does not occur, if $r_j < .5$, w_1 will also be reduced. Even though he behaves strategically, he cannot be sure whether he can keep his current weight unless he knows all other reports. The dominant strategy of the risk-avoider is to report sincerely.

For the risk-taker, increasing the weight is determined by the others' reports as well as his own. Since the state of event A is uncertain, a_2 may report strategically; a_2 will report $r_2 = 1$ when $p_2(A) = .6$ or $r_2 = 0$ when $p_2(A) = .4$. When a_2 reports $r_2 = 1$, and the event occurs, if the others also report $r_j = 1$, w_2 will be unchanged. When he reports $r_2 = 0$, and the event occurs, if $r_j > 0$, w_2 will be decreased. The strategic reporting cannot ensure anything about the risk-taker's relative weight unless he knows all other reports. The dominant strategy of risk-taker is also to report sincerely. Since strategic reporting cannot give any benefit to the field agents, they behave sincerely regardless of risk preference.

The structure of an organization is not an immutable given, but rather a set of principles over which the top manager exercises considerable choice. This study has analyzed four simple models of organizational structures. The impact of organizational structure is critical in information processing: it determines what kind of information the organization can get; it decides what kind of aggregation procedures the organization should follow; it affects how much cost the organization as well as the top manager need to pay for evaluating information; it determines how efficient and reliable the organizational information processing will be; and finally, different organizational structures may result in different organizational predictions. The results of this research give directions on how to understand the effects of organizational structures on information processing and how to design organizational structures with regard to information cost and event predictability.

Several different directions for further research can be drawn from the implications of this analysis. First, this study has assumed that the field agent's utility is the function of his relative influence on information aggregation. If the field agent's utility is a function of several variables, not one, such as income and leisure as in the principal-agent framework, is it possible to design a Bayesian incentive compatible mechanism? How can the relative weight rule be applied to ensure honest reporting? When the manager considers both the relative weights of the reports and the relative importance of their jurisdictions, how can the reports be aggregated? If the relative weight rule is still useful, how can it be modified to include these two factors?

Second, since this study has assumed that there exists a direct feedback process and that information processing is continuous through the time dimension, we can expect that both the field agents and the top manager do not want to deviate from the dominant strategies, and that honest reporting is guaranteed. But if there is no direct feedback or if the event does not recur, how can the organization get honest reports from the field agents? In multi-time information processing game, we need to consider the other factors such as discount factors and risk preferences. When including these variables into the game, the utility functions and reporting strategies of the field agents need to be more specified. Also when the managers who want information to support their own bias, how does this fact influence to information processing and aggregation? If there does not exist an incentive mechanism, what kind of organizational structure is more appropriate with regard to information cost and event predictability?

Finally, this study considers only the problem of aggregating probabilities in organizational structures. Hammond (1986, 1991a, 1991b, Hammond and Thomas 1989) argued that different organizational structures generate different policy outcomes. If information is not probability but policy preferences, how can the top manager apply the relative weight rule as the aggregation rule? Also how can compare organizational structures with regard to information cost and information predictability?

Organizational structures affect the processing and aggregation of information within organizations. Different organizational structures transmit different reports to the top manager. To design an organizational structure is to determine a set of information aggregation rules, and to give emphasis to different principles of information processing.

Each organizational structure has its own unique characteristics with its own information costs and event predictability.

This research concentrates only on the processing and aggregation of probabilities within organizational structures. For better understanding the workings and impact of organizational structures, the other kinds of information processing and organizational functions via organizational structures need to be studied.

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