Information Technology

and the

'New Managerial Work'

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Abstract

Information technology capital now accounts for over 40% of all capital spending while new forms of economic organization, both within and among firms, are emerging. This essay models the "new managerial work", which features a reliance on delegated decision-making and performance pay, as an optimal organizational response to advances in information technology. The technology has automated many routine tasks while accentuating the "information explosion" that increasingly overwhelms top management. The model predicts an increase in decentralization and performance pay in two steps. 1) The growth of inexpensive, but economically valuable information both enables and necessitates the decentralization of organizational information processing and decision-making, and 2) effective use of distributed information processing requires that employees face more outcome-based incentives and fewer rewards based on pre-specified behavior. The analysis also indicates that there is a technological basis to the growth in the number of "knowledge workers" and the decline in the use of rigid work rules.

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> In the post-industrial society, the central problem is not how to organize to produce efficiently (although this will always remain an important consideration), but how to organize to make decisions -- that is, to process information.
>
> - Simon (1976)

1. Introduction

1.1 The new organization of work

By all accounts, the past decade has witnessed dramatic changes in management practice. Even as top management is being given access to a flood of detailed information, the Taylorist model of rigid top-down control and carefully itemized work rules is giving way to a new organization of work characterized by 1) the decentralization of decision-making authority and 2) the increased use of pay-for-performance.

The new pattern of decentralized decision-making has been compared in scale and scope to the organizational changes associated with the earlier industrial revolutions. Piore & Sabel (1984) write of a "second industrial divide" between centralized mass production and knowledge-intensive "flexible specialization". Drucker (1988) calls it the "third period of change: the shift from the command-and-control organization...to the information-based organization, the organization of knowledge specialists". Aoki (1990) adds that

> "the tendency towards the delegation of decision-making to the lower levels of organizational hierarchies, where economically useful on-the-spot information is available, as well as the non-hierarchical communication among operating units, is becoming a more discernable phenomena on a world-wide scale, wherever conditions permit."

The business press is more graphic, referring to "the information revolution [that] has rendered centralized, inflexible bureaucracies -- public or private -- obsolete and

inoperative. Decentralization, individual autonomy and choice have become the watchwords of this new era." (Schlossstein, 1990). If the omniscient control by top management was once feared, the mood in the executive suite today is more aptly symbolized as "Thriving on Chaos", the title of the bellwether "Handbook for a Management Revolution" (Peters, 1988).

Coupled with the decentralization of decision-making is dramatically increased use of pay-for-performance for lower level employees:

> A few things we all used to know about pay: wage earners got paid strictly by the hour. Salary earners got paid by the year. And executives -- only executives -- got bonuses. It was a simple system, seemingly logical, and it worked well for decades. Who would want to change it? Answer: Thousands of managers who have decided that it doesn't work well enough. (Perry, 1988).

Baker (1990a) provides data from the American Productivity & Quality Center that 75% of employers now use at least one form of "bonus" pay plan, and that 70% of these were implemented within the past five years. A more recent survey by the consultants Towers Perrin (1990) found that half of the monetary incentive plans for lower level employees came into being in the past two years.

The emerging best practice has been extensively documented in field studies by Kanter (1987, 1989a, 1989b), who dubs the collective changes the "new managerial work". However, while she notes that "such changes come highly recommended by the experts", she laments that "so far, theorists have given scant attention to the dramatically altered realities of managerial work in these transformed corporations." (Kanter, 1989a)

Is the "new managerial work" just the latest management fad or does it have a sound basis in economic theory?

In this paper, I establish a theoretical basis for the new work in the information processing role of the firm. I explore the proposition that the decentralization of decision-making and the increased use of performance pay are both symptoms of the growth of information work associated with the burgeoning capabilities of the new technologies for collecting and disseminating information. Initially, I abstract from incentive consideration and show that technological advances have reduced the costs of distributing decision-relevant information to the work force. At the same time, the potential for more centralized decision-making has been limited by the bounded capacity of top management to assimilate more information, leading to an increase in the number of knowledge-workers hired. The net result has been a decentralization of the decision-making authority. When incentive considerations are reintroduced, I show that line workers with better information and greater authority have greater flexibility in their actions and will optimally receive more output-based compensation. Thus, this approach accounts for two of the key characteristics of the new organization of work: more decentralized decision-making and more incentive pay for line workers; and it provides a technological basis for these organizational changes: the rise of information technology.

1.2 The technological basis for the new organization

In looking for the basis of the current organization transformation, information technology is an appropriate candidate for three reasons. First, compared to other explanations, the advances in information technology have a particularly reasonable claim to being both novel and exogenous. Many of the fundamental technological breakthroughs that enable today's vast information infrastructure were made less than a generation ago and were driven more by progress in physics and engineering than business demand[1]. Secondly, growth in information technology investment is of a large enough magnitude to be economically significant. Currently, over forty percent of new capital investment in

the U.S. is spent on information technology, resulting in a tenfold increase in its share of total capital stock since 1970 (Brynjolfsson and Bimber, 1989). Meanwhile the quality-adjusted price of computers has declined 6000-fold in the past thirty years (Gordon, 1987). The result has been what is commonly referred to as the "information explosion" -- the number of words of information produced for human consumption more than doubling every eight years. (Pool, 1983)

Thirdly, there is sound basis for expecting an association between the costs of technologies that manage information and the organization of economic activity. The firm and the market have each been frequently modeled as primarily information processing institutions (see Galbraith, 1977, and Hayek, 1945, respectively). Furthermore, recent broad-sample econometric work has specifically established the existence of strong association between investments in information technology and important metrics of economic organization such as firm size and vertical integration (Brynjolfsson, Malone, Gurbaxani & Kambil. 1989), and the number of managers per firm (Brynjolfsson, Malone & Gurbaxani, 1988). The statistical relationships are consistent with case study evidence that information technology has caused significant changes in the organization of work (Zuboff, 1988; Malone, Yates and Benjamin, 1987).[2]

1.3 Information economics as the methodology

In suggesting that the origins of the new organization of work lie in information technology, I am far from alone. However, I will examine an economic interpretation for this relationship, as opposed to the sociological and political theories that have been more common. Although the principal-agent theory on which I draw is commonly classified under the rubric "information economics", scholars have rarely applied it to the practical analysis of information technology (Gurbaxani and Whang, 1989). The hope is that this approach will enable a parsimonious and rigorous explanation of the changing organization of work.

Furthermore, using self-interested but boundedly rational agents to model the organization generates new insights into the implications of these changes and highlights some fundamental similarities between the "new organization" and some familiar old organizations.

Holmstrom makes the point that one must distinguish two types of information costs, 1) those that result from a limited ability to process information, and 2) the "strategic" costs associated with providing incentives for properly transmitting or using private information.[3] Most of the work in information economics has focused on the latter (Holmstrom, 1985). Obviously, considering only the incentive-based information costs can be misleading when applied to the case of information technology. For instance, the mechanism design branch of agency theory can lead one to conclude that greater centralization must inevitably result from lower information costs (Melumad & Reichelstein, 1987).[4] Similarly, most applications of the moral hazard branch stress the idea that better information will necessarily lead to a reduction in incentive pay (Eisenhardt, 1989).

The agency theory model I use in this paper is consistent with earlier applications of the approach. However, the result that better information leads to more incentive pay seems to contradict earlier results only because unlike previous analyses, I focus on the possibility that it is the agent, not the principal, who becomes better informed.

To understand the relative impact of improvements in information technology on principals and agents, one must explicitly consider the limits on attention, and the costs of information processing and transmission in general. Unfortunately, the work on formally modeling the organizational implications of information processing and transmission costs has been quite limited. Marschak and Radner (1972) provided the first serious analysis using "team theory" and more recently Malone (1987, 1988) has modelled the effect of changing these costs on a variety of

organizational prototypes. Malone's models in particular come closer than incentive-based models to tracking the actual organizational changes associated with past changes technology and suggest the potential of this methodology.

Ultimately, one must consider the costs of both information processing and incentives to understand the determinants of organizational structure. Fortunately, when even simple adjustments are made to the basic principal-agent models to account for the fact that human information processing capacity is finite, the theory provides a surprisingly useful framework for understanding the organizational changes engendered by information technology. One can reasonably model the phenomena which comprise the new managerial work as the rational contractual responses of self-interested parties responding to improvements in the quality of their information[5].

1.4 Related literature on the changing organization of work

This paper has been especially motivated by the observations of Rosabeth Kanter, who has done extensive field studies on the emerging practices. She notes that they represent a "postentrepreneurial" ideology in that they involve the adoption of entrepreneurial flexibility and rewards throughout even large businesses, replacing the more bureaucratic structures that have succeeded in the past. Although she attributes the immediate cause of the transformation to "increased competitive pressures", it seems likely that its origins have a deeper basis. While it is true that fiercer competition leaves less room for slack, bureaucracy and centralization are not necessarily equivalent to slack. Until recently, the success of giants like General Motors in managing vast bureaucracies, "rationalizing" production with extensive planning, and achieving economies through long, dedicated production runs was considered the prototype of excellence (Chandler, 1977). There is a near consensus that success today requires not more aggressive application of traditional methods but rather an entirely different approach: a culture that encourages initiative and

innovation by employees, reduced management oversight and rules, and increased use of performance-based rewards (Peters, 1988).

While Kanter's field work has provided one of the most comprehensive descriptions of the new managerial work, others have described and analyzed related aspects of the transition and advanced complementary hypotheses. Piore and Sabel (1984) argued that mass markets are being exhausted, leading to growing instability and the need for more flexible, specialized production and consequently less rigid hierarchies. Using similar reasoning, Dumaine (1989) concludes that new institutions are required to keep up with "the accelerating pace of economic change." Milgrom and Roberts (1990) show that a technological time trend which facilitates flexible manufacturing can lead to a host of other institutional changes, if one assumes that the production function is superadditive in these factors. On the issue of the growing use of pay for performance (a nearly ubiquitous feature of optimality in agency models), Baker, Jensen and Murphy (1988) argue that the that real puzzle is why it hasn't been used even more. Jensen argues further that the traditional organization of public corporations inevitably provides duller incentives than the more recent institutional innovations,[6] and will eventually be eclipsed as the market makes this more apparent (Jensen, 1989). Baker (1990a) documents the rapid growth of pay-for-performance and argues in a principal-agent model that it could be caused by reduced opportunities to use promotions as an alternative source of incentives.

There are three papers that are particularly relevant to the current research. Holmstrom's (1989) article an agency costs and innovation argues that to get workers to innovate, firms must reduce restrictions on their activities and increase their incentive pay. Zuboff's book (1988) provides a wealth of detail on the changes in work organization associated with the large scale introduction of information technology in a variety of firms. Zuboff documents a link between information technology and improvements in workers' information and associates this with an

increase in their power relative to their supervisors. Finally, Malone and Smith (1988) analyze how the use of electronics has changed the cost structure of a number of organizations and predict an evolutionary shift from hierarchies to markets as a result.

1.5 Outline of the paper

The remainder of the paper is organized around two questions. When will information technology lead to decentralization of decision-making authority? How will information technology affect the optimal incentive contracts and the use of performance pay?

In section 2, I argue that the growing availability of inexpensive machine-generated information can facilitate improvements in the information of line workers. However, it has also resulted in growing complaints of "information overload" at the top levels of management, which previous models have ignored (Clippinger and Konsynski, 1989).[7] As a result, the growth in information work has lead to the delegation of increasing amounts of the information processing tasks to agents. The results of the model are shown to be consistent with studies of the comparative advantages and disadvantages of computers in various information processing tasks, and of the growing demand for knowledge workers.

In section 3, I show that the increased information available to the agents leads to their "empowerment" in the sense that they have more flexibility to carry out actions. Their increased flexibility, in turn, limits the ability of the principal to control their actions directly and leads to increased discretion and performance-based pay while reducing hierarchical control and compensation based only on adherence to detailed work rules.

In section 4, I conclude with a summary of the main results and a discussion

of their implications for managerial practice.

2. Decentralizing decision-making

> The scarce resource is not information, it is the processing capacity to attend information. Attention is the chief bottleneck in organizational activity, and the bottleneck becomes narrower and narrower as we move to the tops of organizations.
>
> - Simon, 1973

> First, they get us to buy computers so we can get more information. Then the computers give us more information than we can ever read.
>
> - Bulkely, 1989

2.1 Introduction

A recent article on accounting and control systems marveled that advanced information systems were now providing the management of one chemical plant with the values of over 40,000 variables every two hours (Kaplan, 1989). From a political perspective, it is easy to see the potential of information systems to radically enhance the power of central management by enabling them make more informed decisions and to monitor compliance with those decisions (Pfeffer, 1978).

While there have been some examples of greater centralization via information systems, the reality of the "new managerial work", as described above, stresses the decentralization of authority in successful firms. Even Roger Smith acknowledged the growing consensus regarding technology, management and the locus of decision-making on his last day at the helm of General Motors: "Manufacturing technology is undergoing tremendous change. The whole approach is undergoing a big revolution... You've got to get decision-making pushed down to where the action is." ("Roger Smith Reflects", 1990)

The new managerial work at first appears to be a paradoxical response to advances in information systems. If top management now has access to so much better information than before, why is there such growing pressure to reduce its decision-making authority?

The paradox begins to fade when one recognizes that improving the information of top management is (at best) only half the story. Although the rapid growth in information processing has long been foreseen (Leavitt & Whisler, 1958), the implications for organizational structure, particularly with regard to the question of centralization versus decentralization, are more complex than was originally thought (Attewell & Rule, 1984). On one hand, cheaper information can provide top management with more of the data needed to make decisions, issue instructions, and monitor the compliance of the work force. On the other hand, however, it can provide lower level workers with the information they need to make decisions without the need for as much top management direction. Furthermore, the growing flood of information increasingly requires the delegation and broader distribution of decision-making, lest it overwhelm top management.

2.1.1 The theory of the firm and the locus of decision-making

To understand why decision-making is becoming more decentralized, it is worth looking at the reasons for centralizing in firms in the first place. The nature of the authority relation in firms is still not well-understood by economists although it has been over fifty years since Coase posed his seminal question: why shouldn't all transactions be carried out through the decentralized market mechanism (Coase, 1937)? Despite the theoretical pareto-optimality of completely decentralized decision-making (cf. Bator, 1957 and references therein) in the absence of transaction costs, the reality is that many of the important resource allocation decisions in the United States take place within firms, under the direction of management's "visible hand".

Coase (1937), Simon (1957) and Williamson (1975, 1985) have each cited the employment relation -- workers responding to the commands of their superiors -- as the defining characteristic of firms. Even within firms, there are varying degrees of control exerted by top management. At its most extreme, traditional manufacturing in the Taylorist tradition can be characterized by the rigid distinction made between the decision-maker and the workers, the "separation of conceptualization and execution" (Sabel, Kern and Herrigel, 1989). The philosophy is epitomized by the "first law of scientific management" laid down at the beginning of the century: "It is necessary in any activity to have a complete knowledge of what is to be done and to prepare instructions as to what is to be done before the work is started...the laborer has only to follow instructions. He need not stop to think." (Meyers, 1914, quoted in Zuboff, 1988). In contrast, a stylized fact about the new managerial work is that fiat is replaced by negotiation and salesmanship, to the extent that even the terms "superior" and "subordinate" seem inappropriate (Kanter, 1989).

Under what conditions will it be efficient to centralize decision-making and coordinate production via "commands"? Coase (1937), and more recently, Rosen (1988) have argued that organizing production within a common firm reduces transaction costs because it insulates agents from "high-powered", market-based incentives and the resulting opportunism and need for haggling.

However, even under the assumption that agent's objectives are completely aligned, it does not follow that decision-making will be centralized. The original team theory models by Marshak and Radner (1972) had no role for commands. In an efficient organization, the function of communication could never be to restrict the feasible set of actions of other agents but only to distribute information that originated at a different location than where it was needed.[8] Indeed, their models implicitly assume that even if a "command" were given, the agent, who has unlimited information processing capacity, could invert the strategy of his superior and deduce the information on which the command was based. However, as Geankoplos and

Milgrom (1985) have pointed out, if one rejects the notion that agents can costlessly derive the justification for any commands they receive, then the stage is set for a model in which it is optimal for subordinates to not even try to understand the reasons for their superior's instructions, but just obey them. Indeed, Geankoplos and Milgrom do construct a sophisticated model that shows that it can be informationally cheaper to give only orders to subordinates instead of all the information that makes those orders appropriate.

At the expense of some generality, the essence of this argument can be captured in a somewhat simpler example. If the optimal actions of n agents each depends on the values of m parameters, then a decentralized solution would call for m reports to each of n agents for an organizational total of mn parameter reports. When information collection and communication are costly, a cheaper solution is for the "boss" to collect the m reports, determine the optimal action for each of the agents, and issue n-1 commands, for a total of m+n-1 parameter reports. This will be unambiguously cheaper than the decentralized solution as long as 1) issuing a command to an agent requires less transmission expense than providing the agent with the values of the m data items, and 2) the information collection and processing costs of the boss are no more expensive than the corresponding costs of the agents.

Centralization may also facilitate economies of scale in information collection. Furthermore, when agents have access to noisy, but uncorrelated, signals of the true value of the data items, m, then centralized decision-making can provide a mechanism for pooling the signals and improving its precision. This suggests that in an information scarce environment, centralized decision-making is a natural way to implement the management heuristic "bring as much information to bear on each decision".

Of course, processing all this information to come up with the optimal action for each agent can place a heavy burden on the central decision-maker, but by doing

so he or she can relieve the organization of the potentially costly alternative of providing all the relevant information to each of the decentralized agents for them to compute their own optimal actions. Instead, they need only be provided with relatively low bandwidth "instructions".[9]

Why has information technology so often lead to less centralization of decision-making? It has affected both aspects of the logic of centralization, reducing the costs of distributing information to the agents, and increasing the information load, and therefore the relative processing costs, of centralized decision-making. Each of these effects is discussed more fully in the next two sections, followed by a discussion of the results in section 2.4.

2.2 Information technology and decentralization

Commands can be characterized as a means of economizing on the amount of information that has to be provided to agents before they act. In the example discussed above, centralized decision-making coupled with commands to the agents reduced the organization's information requirements from mn parameter reports to just m reports plus n-1 commands. Whether or not this is a substantial savings to the organization depends critically on the extent to which agents find receiving and interpreting a command cheaper than the cost of receiving m reports. In the environment that gave rise to the large, relatively centralized hierarchies of the major corporations, this was very likely to be true.

However, since the 1960s, the costs of providing many types of information to all levels of the organization have dropped dramatically, for instance, over 6000-fold for computer generated data (Gordon, 1987). As a result, data and reports that were expensive to provide to the agent are now much cheaper, making decentralization more cost effective. Applegate, Cash and Mills (1989), Zuboff (1988) and Malone et al. (1987) find that technologies like computer databases,

electronic mail, voice mail, fax, data networks and video conferencing are increasingly being used to keep agents informed, replacing the more labor intensive alternative of oral and written reports by middle managers, who serve primarily as "information relays" in many organizations (Drucker, 1988). Mohrman and Von Glinow (1990) concluded that this has had a significant effect on organizations:

> [Information technology] enables information to be widely shared throughout the organization, theoretically providing the line worker with sufficient information to work without supervision and to make decisions from a perspective that goes well beyond the individual job.

In the context of the previous example, if an agent can be provided with the m parameter reports upon which his optimal action depends as cheaply as a single command, a key advantage of centralization is negated.

In an environment of scarce and expensive information, giving extensive decision authority to lower level agents could lead to chaos, to the extent that they did not have access to the necessary information on which to base their decisions. However, if it is easy for agents at all levels of the organization to obtain the information the need, it becomes practical to also give them the decision rights associated with that information. As Jensen and Meckling point out, decision rights should optimally be collocated with the relevant information.

2.3 Information technology and centralization

While the preceding argument suggest that information technology reduces the costs of decentralized decision-making, one might ask why the cheaper information should not be used just as effectively by a central decision-maker. Indeed, information technology has sometimes been likened to a "universal solvent" that makes all organizational forms equally inexpensive. If there is a movement to decentralization, however, information technology must be affecting the cost of centralization and decentralization differentially.

2.3.1 Facilitating centralization

Before examining some of the ways information technology may increase the costs of centralization, it is beneficial to look at a simple model of how it can facilitate centralization. This will provide a foundation for subsequent models, and provide insight into those of cases in which the primary impact of information technology has been to increase central control. For instance, an elaborate information system used by Mrs. Fields' Cookies has enabled them to manage nearly five hundred stores nationwide, without franchising and with little skilled labor, while maintaining control of decisions as trivial as how much of each type of cookies to bake each hour, based on locally collected data on market conditions. (Ostrofsky and Cash, 1989).

Consider a firm with n agents indexed by $i = \{1,...,n\}$, each of whom receives a quantity, m_i, of information inputs or data which he transforms into decisions, d_i, at a cost that is a function of the amount of information processed, $c_i(m_i)$. The key organizational parameter is what share of the total information to convey to each agent.

If information technology allows the effectively costless transfer of information between agents, then the final distribution of information need bear no relationship to the initial distribution and therefore the distribution of decision-making will only be a function of the agent's processing costs.

Initially, assume that information processing costs grow only proportionately to information inputs.

$$c_i(m_i) = c_i m_i, \quad c_i(0) = 0.$$

The total costs of producing decisions are $\Sigma\, c_i m_i$.

In this case, it will always be optimal for only one of the agents, (the one with lower information processing costs), to do 100% of the information processing for the firm.[10] This yields a total cost

$$\Sigma c_i(m_i) = c_{min}(\Sigma m_i) = c_{min}\Sigma m_i$$

where c_{min} is the cost of the most efficient agent.

This suggests that to the extent that information technology enables the relatively free flow of information, decision-making authority should flow to whichever agent can most cheaply process the information, while the remaining agents simply follow his or her instructions. As in the case study discussed above, this has sometimes been the effect of information technology on organizations especially in relatively simple industries in which the amount of information to be processed is not too great. Mrs. Fields stores, for instance, are essentially one-product stores, and almost all decision-making is centralized in Park City, Utah via the technology.

2.3.2 Multiple "centers"

Another phenomenon that has been associated with the increasing use of information technology, especially in more complex organizations, is the rise of specialists, who are called on for specific information processing tasks (Crowston, Malone and Lin, 1987). A related change is rise of the "cluster organization" (Mills, 1990), in which different agents are given authority for decision-making at different times, depending on the circumstances. While particular types of decision in such organizations are centralized, taken as a whole, authority is decentralized.

These organizational changes can be easily derived from the above model if one relaxes the assumption that the same agent will be the low cost processor for all

types of data. That is:

$c_i(m) < c_j(m)$, for one type of data

but

$c_j(m) < c_i(m)$, for a different type of data

As information technology reduces the cost of informing agents, different components will optimally be sent to different agents. Each item will go to the agent who is the more efficient processor for that particular type of data, that is, to the "specialist" in that area. In this case, instead of just one "center" there will be multiple centers, depending on how many different specialists exist.

There is still the question of making sure that each data item gets to the right "specialist". A central department can sift through all the data and allocate it those it thinks will benefit from it, but then an additional layer of processing must be added. A brute force alternative is simply to make all the company's data available to all the agents, who select out those components relevant to their decisions. Unless the agents have a way of knowing what each other are working on, this can lead to duplication or leave some items unexamined.

To some extent, technology is increasingly be used to address this coordination problem by enhancing the capacity of the organization to deliver the appropriate information directly to line workers, without going through the bottleneck of the traditional chain of command. For instance, Applegate, Cash and Mills (1989) find that increasingly:

> Computers will also help identify who in the company has the expertise needed to work on a particular problem. Data bases of employees' skills and backgrounds will ensure that the mix of talent can be tailor-made for every task that arises.

To the extent that information technology makes it easier to contact and

work with a broader set of individuals on new projects, it provides further incentives for specialization. Effectively the market for agent's services is broadened, and as the theorem "the division of labor is limited by the extent of the market" (Smith, 1776; Stigler, 1951) suggests, a finer specialization can be supported. The only caveat is that the use of technology thus far is primarily intra-organizational, and the theorem requires that agents face compensation is at least partially output-contingent, so that they will correctly direct their efforts.

Even within firms, the use of technology to coordinate decision-making among various experts is still in its infancy. Only recently has the field of "computer supported cooperative work" been established (see Malone, 1988). Furthermore, many problems are not easily decomposable, as they must be if the processing of the data set is to be effectively distributed.

To the extent that the problem of decomposing and allocating the data is not costless, one might still expect to see centralization of decision-making. The fewer the number of agents involved in decision-making, the less need for inter-agent coordination. There is some evidence that this is an important effect in that businesses are reluctant to hire two part-time managers to do the work of one full-time manager. But businesses also spend a great deal of money training different employees to become experts in different areas. This would seem to increase coordination costs because information must now be allocated to more agents. In the context of the model presented thus far, the firm would be expected to concentrate all its training on one promising agent who could then become the most efficient at all types of information processing. Presumably, the reason firms do not do this is that all agents have limited processing capacity; the costs of processing information eventually become very large as the load increases. This suggests the following modification of the model to take into account the limits on the processing capacity of agents.

2.3.3 The costs of centralization

In the initial enthusiasm to exploit the enormous power of computers, there was a tendency to focus on centralizing information systems to give top management access to as much information as possible (Simon, 1973). Little consideration was give to conserving the processing capacity, or attention, of managers. As Simon has argued, this strategy is implicitly based on the "assumptions of a past society where information rather than attention was the scarce resource." While shifting information about all the firm's operations to a central location can be optimal when agent's processing capacity is unbounded, the need for decentralization arises when the costs of processing all information centrally begin to rise due to capacity constraints. Indeed, the assumption made earlier that human information processing can scale up proportionately is not realistic for very large loads. No one imagines that any single manager of the chemical plant mentioned above could possibly analyze and make decisions based on all 40,000 data items received every two hours. Aggregation and summary statistics can sometimes help, but much knowledge is "specific" and thus becomes worthless when aggregated. Furthermore, a firm that simply ignores the additional information, while avoiding the costs of additional information work, is likely to incur substantial opportunity costs by forgoing chances to profit in new markets, to reduce costs or simply to remain competitive with more enterprising rivals. As a result, the growth in data collected is likely to represent a real, if not always proportional, growth in information to be processed.[11]

The notion of bounded rationality suggests that the cost of processing information by any individual will rise without limit as the amount of information to be processed increases. Adding this condition negates the feasibility of the centralized decision-making schemes that are otherwise very attractive theoretically. Instead, an organization with higher information processing requirements is likely to become more decentralized. This is because human information processing capabilities, unlike those of machines, come in relatively constant granularity.[12]

Beyond some point, additional capabilities are only available by increasing the number of people involved. Although bounded rationality is notoriously hard to model, the following simple example suffices to provide graphic intuition for this basic point.

Consider the two agent case of the model presented above. Even when we assume as before that agent 1 (the "manager") has an initial cost advantage over agent 2 (a "worker"): $c_1 < c_2$, complete centralization does not necessarily follow if costs eventually rise with increase load.

To model this, unlike the previous case, we introduce a simple form of bounded rationality constraining the information processing capacity of each agent: costs of information processing are convex beyond some point, $c'' > 0$, and in the limit, the marginal costs of processing information tend to infinity. For concreteness, consider the quadratic cost function:

$$c_i(m) \equiv c_i m_i + \tfrac{1}{2} k_i m_i^2$$

with arbitrary positive constants c and k.

Minimizing costs implies the following first order condition:

$$c_1 + k_1 m_1 = c_2 + k_2 m_2$$

for all positive values of m_1 and m_2.

Defining the total quantity of information processed by the firm as z ($\equiv m_1 + m_2$), one can rewrite the constraint as:

$$m_1 = (c_2 - c_1)/(k_1 + k_2) + [k_2/(k_1 + k_2)]z$$

or

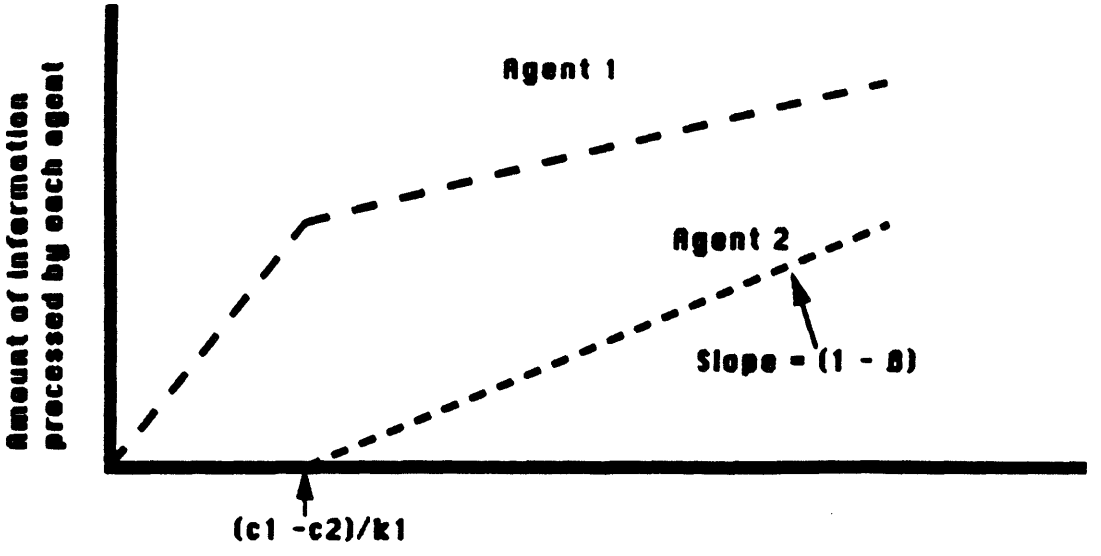
$$m_1 = \alpha + \beta z$$

where $\alpha \equiv (c_2-c_1)/(k_1+k_2)$
and $\beta \equiv k_2/(k_1+k_2)$

By assumption, $c_1 < c_2$ and $k_1, k_2 > 0$, implying that $\alpha > 0$ and $0 < \beta < 1$.

The first order constraint will not be binding for $z < k_2\alpha/k_1\beta$. Up to this point all information will be processed by the agent 1. However, as information processing requirements grow beyond this point, a share $(1 - \beta)$ will be off-loaded to the higher cost agent. (See figure 1)

Figure 1: The increase in the share of processing off-loaded, quadratic cost case with k2 < k1.



The effect is readily generalized to more than two agents. Even if some agents start of with lower costs, as their load increases, their marginal cost will increase until it becomes more efficient to use additional processors. Thus, in the presence of limits on processing capacity, as the information load grows, more of the work is shifted to agents that previously did no information processing and proportionately less is done centrally.

The intuition behind this simple example is straightforward. Distributing

information work may be optimal not because of any inherent organizational efficiencies, but simply as a response to the limited ability of any one human mind to do more than some finite amount of information processing. Given the fact that the ability of humans to absorb and process information varies over a relatively narrow band[13], at least compared to computers, this suggests that if organizations get closer to the theoretical limit of human information processing (i.e. when all its members spend 100% of their time processing information), information work will necessarily be more evenly spread throughout the organization. This does not mean that decisions made at all levels will be "equally important", but it does mean that more agents will be taking action based on their own information and decisions, as opposed to simply following instructions from superiors. Unlike the previous model, this model is consistent with the notion that it is advantageous for the firm to distinguish between different types of information processing, perhaps based on areas of expertise, so that the load could be more evenly distributed. Only when the firm does very limited information processing can decision-making be fully centralized.

It should be noted that when the agents do not all share a common objective function, agency costs will also have to be considered and these will not necessarily be the same for agents who simply follow instructions as for those who decide their actions for themselves. Indeed, as discussed in section 3 below, the agency costs of getting informed agents to work in the firm's interest will generally be higher than the agency costs of enforcing adherence to instructions by less informed agents. While this puts an additional cost on decentralized decision-making, it does not qualitatively affect the preceding analysis. As information processing requirements grow, decentralization will still tend to dominate under the assumption that the marginal cost of processing by individual agents, c', tends to infinity, while agency cost of delegation are bounded. The organizational trade-off is between having the additional information processing done centrally, thereby saving on agency costs or having it decentralized, and economizing on the capacity of any one agent. The

agency costs of delegation will in general be increasing in the amount of information the agent has, but they are bounded as long as the agent is not infinitely risk-averse.[14] In contrast, the costs of increasing the load on any one individual must tend to infinity -- no one can work more than twenty-four hours per day -- so with an increasing information load, the costs of centralization must eventually surpass the costs of decentralization.

2.4 Discussion: Technology, information and work

The conclusion that information processing must ultimately become more distributed as the information processing load increases depends critically on the assumption that the capacity of agents to process information does not grow even faster than the load. The responses of organizations to the introduction of information technology, including the increasing decentralization of decision-making, as well as growing complaints by executives of "information overload" and increased numbers of "knowledge workers" employed by organizations, suggest that the information explosion is indeed putting a strain on human information processing capacity.

Faced with a growing flood of potentially valuable information, the executive has three choices. He can use technology to enhance his ability to process information, he can ignore the information and the opportunities implicit in it, or he can delegate its analysis to another person.

2.4.1 The nature of information technology

Information technology has vastly reduced the costs of collecting, storing and transmitting information, but it has had less of an impact on the equally necessary steps in the information processing chain involving decision-making and judgement

(Van Zandt, 1990). This is not to say that there are not many tasks now done by computers that could formerly be done only by humans. Automation has unquestionable reduced the need for human labor in a number of aspects of the firm's production. However, because machines excel at following well-defined algorithms or rules, and playing out predictable scenarios (Penzias, 1989), the tasks automated are often precisely the ones that formerly could most easily be delegated to subordinates anyway, so the net result is not much of a savings at the "bottleneck" of decision-making. Instead, the consequence is a decline in work that is "delegatable" to other people via detailed instructions and an increase in relative share of "knowledge work" that must be done. In particular, the aspects of human decision-making that involve judgement, handling exceptions, and pattern recognition are recognized as being particularly hard to automate. As a result, it would be a mistake to presume that human and machine information processing are substitutes for one another in those areas of the firm where information overload is most serious. New technologies are replicating more of the decision-making capabilities of humans[15], but for the foreseeable future, computers and humans will continue to have markedly different strengths, and this has lead to a natural division of labor in which computers typically provide information to humans who in turn analyze the information and make decisions.

To the extent that these tasks are each necessary for problem-solving, or at least complementary, the decline in the price of one will lead to increased demand for the other. This is exactly what seems to be happening. For instance, consider a firm that could increase profits by $400,000 by analyzing 40,000 items of data. If the data items cost $10 each to collect, store and transmit, then there is no point gathering or processing them. But if the data items cost only $9.00 to collect, store and transmit to an analyst, then the firm will willing to spend up to $40,000 to hire an analyst. As the cost of "information" declines, the demand for "judgement" increases, to the extent they are complementary in nature.

Even a machine processing advance that, in isolation, appears to decrease the requirements for human information processing, can ultimately lead to an increase in human information processing in equilibrium as the firm shifts to more information-intensive ways of doing business.[16] Furthermore, when a firm's competitors, suppliers or customers increase their information processing throughput, they put renewed demands on the firm's own capabilities. For instance, Wall Street firms have been describe as waging a veritable "arm's race" of information processing technology (Wall Street Computer Review, 1990).

2.4.2 Evidence of "information overload"

The increasing availability of information that can be profitably attended to, coupled with no corresponding increase automated decision-making or in hours in the day, has created a growing sense of "information overload". According to Stalk and Hout, (1990) and Clippinger and Konsynski, (1989), the information-starved top executives of the 1950s have been supplanted by the information-flooded and time starved executives of the 1990s, largely because of advances in technology. Similarly, Bulkely (1989) bemoans the consequences of "data overload: computer users get[ing] too much of a good thing". The sense of overload is consistent with statistics that show that between 1960 and 1977, the number of words made available to Americans through 17 major communications channels grew by 8.9% annually, while the number of words actually read grew at less than 1/3 that rate (Pool, 1983). Pool finds that much of the growth in information generated is as a result of a switch from print to electronic media, and that most of the relatively small growth in consumption is accounted for by the shift from blue- to white-collar employment and the rise in educational levels. Interestingly, he also detects an significant increase in the proportion of point-to-point communications as opposed to mass media. The intuition that cheaper transmission of information coupled with relatively modest advances in the ability of humans receivers to process information will lead to information overload has been formalized by Van Zandt (1990).[17] The

opportunity costs of missing valuable information because of overload can be substantial.

2.4.3 Evidence of the rise in knowledge work

A recent analysis of occupational data (Loveman, 1989), found that the share of skilled workers has increased dramatically in recent years in the United States, Germany, and Britain, and that this increase is closely associated with the introduction of new technologies and organizational forms. Furthermore, despite a significant increase in the supply of college-educated people entering the workforce, their wage premium over less skilled workers has not declined, implying a shift in relative labor demand. This is consistent with increased information processing requirements in firms, and confirms earlier studies that found an increasing share of the labor force is engaged in occupations requiring high skills (Swasy and Hymowitz, 1990) and in information work in general (Porat, 1977).

While there have been substantial declines in the relative demand for blue collar workers (Blackburn, Bloom and Freeman, 1989), the evidence does not suggest that computers have (as yet) significantly reduced the demand for even low-level information workers. As late as the mid-1970s, investments in computers were found to be associated with a complementary increase in the employment of even the clerical workers whose jobs were thought to be most vulnerable automation (Osterman, 1986).

While the growth in the share of knowledge workers in firms is in some sense prima facia evidence of more decentralized information processing, there is evidence that job classifications understate the decentralization of decision-making in the firm. There are widespread reports that employees have increased responsibilities even without any changes in their titles (Halal, 1986; Zuboff, 1988). The situation at AT&T is typical:

> Cathy Ann Gallo, manager of AT&T's Phone Center in Summit, N.J., used to need approval before she could do something as simple as replace a broken phone. Now, higher level managers...do not have time to flash green and red lights on all decisions. "I've been empowered to do whatever makes my customers happy, " Ms. Gallo said. (Deutsch, 1990)

One key aspect of the new managerial work is the decentralization of decision-making authority. In this section we've seen how the increased information processing opportunities available to the firm, coupled with the bounded capacity of any one person, naturally leads to more distributed decision-making.

Another key aspect of the new work is increased use of performance incentives. As Jack Grubman, Paine Webber's telecommunication analyst, said of the AT&T restructuring described above, "They've made culture change a pocketbook issue and that's a really smart move". AT&T now offers profit-sharing to all its employees and pay is more closely linked to performance. Before, "AT&T workers used to be judged on how well they follow orders." (Deutsch, 1990)

In section 3, I show why performance pay must also be increased when the information available to employees increases.

3. Optimal incentive contracts for information workers

> An individual without information cannot take responsibility; an individual who is given information cannot help but take responsibility.
> - Jan Carlzon (1987)

> Leaders in the new organization do not lack motivational tools, but the tools are different from those of traditional corporate bureaucrats. The new rewards are based not on status but on contribution, and they consist not of regular promotion and automatic pay raises but of...a share of the glory and the gains of success.
> - Rosabeth Kanter (1989)

Under what conditions will firms optimally pay fixed wages for the completion of prespecified tasks? When will incentive pay be required? As suggested in the previous section, the answers to these questions depend critically on the information available to the firm and to the worker. In particular, when the information available to the firm (hereafter referred to as the "principal") is a superset of the information available to the worker (the "agent"), no performance pay for the agent is required in the optimal contract. The agent will simply be compensated for the input he provides: work effort. However, when the agent has information that the principal doesn't, the optimal contract will include a component of compensation that is linked to the consequences of the agent's actions, the output. This is true even when those consequences are partly beyond the agent's control.[18] It is worth noting that in traditional hierarchies, supervisors are generally presumed to know more about the job than the people being supervised do. In contrast, the new managerial work typically involves employees who often have more information about the work than their managers.

The situation in which an agent working for a principal obtains private knowledge relevant to their relationship is commonly referred to as "moral hazard".[19] Moral hazard problems can be further classified as either problems of "hidden action" or "hidden information". In hidden action problems, both parties have the same knowledge about the state of nature[20], but the principal does not have precise knowledge about the action (or effort level) of the agent. In hidden information problems, the agent's actions are observable, but they may be based on information available only to the agent, so only he knows whether they were truly appropriate.

The information and production technologies of the firm are the primary determinants of the relative amounts of information available to the principal and the agent. In particular, information technology can be used to increase the relative information of the principal, and if she[21] is able to absorb and use the additional

information, this will make fixed wage contracts more feasible. As discussed in section II, however, the information explosion can also lead to a greater reliance on decentralized information processing, which would tend to exacerbate moral hazard problems.

In this section, I discuss how changes in the information structure of the firm lead to concomitant changes in the optimal contracts between firms and their workers. I begin with a discussion of why performance based pay is unnecessary when the principal has all the information that the agent does, but becomes necessary when the agent has private information. I then examine the role of information systems in affecting the relative information of the principal and agent. Next, I present a model demonstrating the optimality of increasing performance-based pay when the amount of the agent's private information increases. Section 3.4 extends the results to the multidimensional case, in the spirit of Holmstrom and Milgrom's (1990) model. I wrap up with a qualification of the meaning of performance pay and a summary of the results of this section.

3.1 Forcing contracts and incentive contracts

3.1.1 Symmetric Information

When the agent's effort level is fully observable and the agent and the principal have symmetric information -- neither party knows the true state before the agent's action, or alternatively, both do -- then the optimal contract does not require any "performance pay" to motivate the right actions by the agent.

When neither party has knowledge of the true state before the effort level is chosen, the optimal effort level can be calculated in advance by the principal.[22] If the principal is effectively risk-neutral (for instance, if the firm is "large" or because its shareholders can diversify their risk), and the agent is risk-averse, then a "forcing

contract" that pays a flat wage to the agent for meeting or exceeding a prespecified effort level and nothing for falling short of this level will achieve the first best level of effort and risk sharing (Harris and Raviv, 1979). This can be likened to the typical authority and compensation relationship of a "traditional" firm, in which the a supervisor determines what work must be done and pays a flat wage to the employee contingent on his action, but not on the outcome. The agent's pay is not affected by the ultimate impact of his actions on the firm's output. All of the risk will be born by the principal.[23]

When the state is known to both parties before the agent chooses his effort level, pay will vary more, but in a fairly straightforward way. The principal can calculate the optimal effort level for the state that actually obtains by requiring that the marginal benefit of any additional effort just equals the extra costs incurred. As above, the agent will be paid only for meeting, or exceeding, the level prespecified by the principal. Although the principal may require a different level of effort in each state, she will also adjust the agent's pay just enough to precisely compensate him for the change in effort requirements, leaving him with constant utility regardless of the actual state.[24]

This situation -- a fully informed principal who specifies exactly the actions to be taken by the agent and pays a wage that provides a constant utility level to the agent -- achieves the "first-best" levels of output and risk-sharing, meaning that given the available information, no change in the effort levels or the way output is apportioned between the parties can make both parties better off.

The authority and compensation relations in the full information case are similar to those in the no information case. The supervisor specifies the tasks to be completed and the agent is paid a fixed wage for a given job. The main difference is that as the complexity of the environment and pace of change increase, management will have to prespecify an increasing number of contingent tasks. As a

result, enforcing the optimal contract in the full information case can tax the information processing capacity of the supervisor and will require complex, complete contracts and work rules that can limit flexibility and initiative.

3.1.2 Asymmetric Information

In contrast to the symmetric information cases, when the agent has information about his actions or the state of nature that the principal does not, it may be necessary to provide incentives for the optimal action by basing compensation on output. In general, it will not be possible to achieve the "first best" levels of both effort and risk-sharing that were possible when the principal had no less information than the agent. Although the exact form of the compensation scheme is very sensitive to the assumptions made about the production technology and the precise information available to each party, typically the agent will be paid a bonus for good outcomes and have his pay reduced for bad outcomes, even though the outcomes are only partly within his control.[25] The problem is that the principal cannot insure the agent against events beyond his control without also eliminating the agent's incentive to choose the right level of effort.

An extensive literature documents the fact that these agency problems can be quite significant. Generally the only way for the principal to completely eliminate the agency problems is to improve her information. This creates a role for monitoring information about the agent's actions or the environment, but also increases the cognitive load on the principal.

3.2 The role of information

3.2.1 Information systems and control

Research on the value of information in moral hazard problems has

emphasized the following proposition: any signal that potentially provides information about an agent's action, (up to a sufficient statistic), will have positive value and should, in general, be included in the optimal contract (Holmstrom, 1979). The basic results of this literature have often been stylized as a trade-off between the costs of better information systems versus the higher agency costs of outcome-based contracts (Jensen & Meckling, 1976; Eisenhardt, 1988).
For instance:

> "The principal has two options (Demski & Feltham, 1978): (1) to discover the agent's behavior by investing in information or (2) to contract at least partially on the basis of the outcomes of the agent's behavior." (Eisenhardt, 1988)

This view stresses that the need for performance pay would be eliminated if the principal had good enough information to monitor the agent's actions. Ideally, the principal could tell the agent exactly what to do, and write a "forcing" contract that got the agent to do it, without any recourse to outcome-based compensation schemes that transfer risk to the agent. This suggests that the imperfection of information systems is what makes performance-pay, and the attendant agency costs, necessary.

With proper incentives, the agent will voluntarily reveal the private information that the principal seeks. Of course this requires access to a communication channel, but this can be a cost-effective alternative when monitoring is impossible, or very expensive. Considerable progress has been made in understanding under what conditions the principal can induce the agent to voluntary reveal his private information.

An important implication of this research is that in the absence of communication costs, "any mechanism involving delegation of decision making can, without loss of performance, be replaced by a completely centralized mechanism"

(Melumad & Reichelstein, 1987). This is commonly referred to as the "revelation principle" and simplifies enormously the theoretical analysis of alternative mechanisms for organizing economic activity.[26] The key point in Melumad & Reichelstein's paper is that, given certain incentive and spanning conditions[27], the principal can always "reverse engineer" the agent's private information from the action that the agent took, so for ease of modelling, one can assume that the agent directly reveals his private information. While the revelation principle was developed as an aid to theory development, Green notes that "it has been suggested that the revelation principle may serve as a practical basis for the design of particular institutions" (E. Green, 1984). For instance, Kirby draws the following implication from Melumad & Reichelstein's work: "...the larger the costs of communication, ceteris paribus, the more likely that the organization will prefer a delegated decision mechanism over a communication-based centralization mechanism." (Kirby, 1987)

3.2.2 Information technology and delegation

The agency literature on reductions in monitoring and communication costs can be interpreted to show that improvements in the quality of information and communication technologies will necessarily lead to greater centralization. This conclusion, however, is wrong. The principal may not want better information on the agent's actions or knowledge. Providing the principal with better information is only valuable to the extent that she can process it. But as was shown in section II, the whole reason for hiring agents to do information work in the first place may be to alleviate the information processing load on the principal. It would make no sense to hire a middle manager or specialist and then make all the decisions for him. Yet this is precisely the implied solution of the argument for increasing the principal's information in the agency literature. Similarly, the "panopticon" approach of using information technology to monitor workers implicit in much of the literature on applied information systems makes less sense when the principal is already

overburdened with data. The critical, if generally unstated, assumption underlying the revelation principal and much of the more recent work is that the principal has unlimited, costless information processing capacity. This assumption is not appropriate for organizations of information workers.

More informed agents

While the above approaches are useful in explaining circumstances in which information technology is used to more closely monitor workers, there is an alternative case: information technology that is used primarily to increase the information available to the agents. In section II, it was found that when the ability of the principal to assimilate and use new information is not infinite, an increased information processing load will tend to be more broadly distributed to the agents. When information technology increases the need for human information processing in this way, it can create, or exacerbate the need for performance pay associated with hidden information moral hazard problems.

Work that is less observable

Furthermore, information technology can also make it harder for the principal to monitor the agents actions, thereby creating or exacerbating hidden action moral hazard problems. For one thing, it is generally much harder to gauge the effort level of an agent engaged in mental work than physical work and as a recent report concluded: "The computer-based technologies of the future will place even greater demands on the mental rather than the physical capabilities of factory and office workers", (Cyert & Mowery, 1989). Zuboff (1988) documented the frustration of factory managers at "Tiger Creek" who were no longer able to judge the effort level of their subordinates when the job content changed from physical activities to making decisions in a computer automated factory. At the same time, information technology has often made it easier to tabulate and record the physical

output that ultimately results from an agent's actions.

Greater flexibility

In many organizations, there is also an increase in the number of different types of activities performed by each agent as computers enable flexible manufacturing (Sabel, Kern & Herrigan, 1989) A principal may have a harder time monitoring agents who engage in a broad variety of activities because good summary information cannot be as easily created. As Kaplan (1989) stresses, overhead monitoring and management costs increase rapidly as the number of activities increases and product cycles shorten.

3.2.3 Summary of information technology's effects

From the above discussion, it is apparent that the potential impacts of information technology on the optimal contracts between workers and firms are varied. Information systems can be used to improve monitoring, enabling the principal to take more control of the agent's actions and mitigating the need for performance pay. But as a practical matter, the growth of information systems can also increase relative information available to agents and the flexibility that they have in choosing their activities. Each of these effects have been observed following the introduction of information technology (Attewell and Rule, 1984).

3.3 Performance pay as a response to improved agent information

While improvements in the information of the principal have been formally analyzed extensively in the agency literature, far less attention has been paid to the organizational impacts of improving the agent's information and flexibility. Below, I show how increasing the agent's information about the state of the world can necessitate an increase in the output-based component of his compensation.

Surprisingly, this is true even when the information that the agent gathers has no value to the principal and she is not attempting to benefit from it. In section 3.4, I show how giving the agent new options, either explicitly, or as a result of improved information, can negate the effectiveness of incentive contracts based on fewer agent options. Like the first model, the multidimensional model demonstrates that the optimal contract requires an increase in the output-based component of pay.

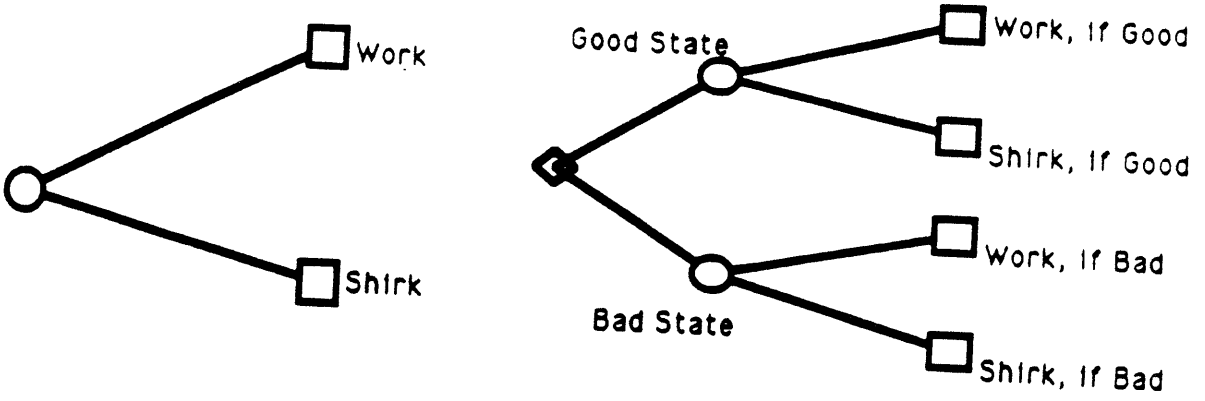
While these results are in many ways diametrically opposite to those of the previous literature which emphasized improving the principal's information, they follow from reasonable assumptions and are consistent with many of the actual changes in organization.

3.3.1 The basic model

The basic idea is to consider a moral hazard problem with both hidden actions and hidden information; the agent obtains some private information which affect his unobservable choice of effort level. As the agent's information improves, he is able to distinguish among states of nature that previously were lumped together. Because he can now condition his actions on more distinct states, his flexibility increases. In particular, with better information in the Blackwell sense, the space of state-contingent actions available to the agent is a strict superset of his previous action-space. Note that this is true even if the number of actual, "physical" actions does not change. This is illustrated for the 2-state, 2-action case in figure 2.

The increase in flexibility enabled by the improved information can be very valuable to the extent it allows the agent to tailor his actions to specific circumstances and thus pushes out the frontier of production possibilities. However, there is also a second, less obvious effect. The agent's increased flexibility makes it harder for the principal to predict and control his actions. The narrow, specific instructions and rewards that worked before may now end up being counter

Figure 2: How Information Can Empower
Increasing the number of
state-contingent options



productive because they prevent the agent from taking full advantage of his information, or worse yet, they may encourage the agent to "game" the system by meeting the letter of the instructions in ways that were not intended.[28] As a result, the principal will find it increasingly necessary to pay the agent as a function of the net output of the agent's actions, even if some aspects of this output are beyond the agent's control. This can lower welfare as opportunities for risk-sharing between the agent and the principal are diminished.

In principle, these two effects, 1) a greater production set but 2) more difficulty in controlling the agent, are separable. For instance, as demonstrated below, it is entirely possible for the improvement in information to do nothing to increase production possibilities yet still decrease the ability of the principal to control the agent.

The optimal contract can be analyzed as a constrained maximization problem for the principal. Maximize her utility subject to two types of constraints 1) the agent must get some minimum level of utility (the participation or individual rationality constraint: "IR") and 2) the agent must find it in his interest to do the

posited actions given his information (incentive compatibility constraints: "IC"). The main effect of the agent's improved information will be on the IC constraints. The increased flexibility of the agent means that the principal must satisfy additional IC constraints lest the agent choose an action other than the optimal one. Meeting these additional constraints will, in general, require more incentive pay and worse risk-sharing.[29]

This effect can be illustrated in a model with two randomly determined states of nature ($\Theta \in \{B,G\}$), two levels of effort chosen by the agent ($a \in \{L, H\}$) and two possible outcomes ($x \in \{0,1\}$). The probability of a successful outcome ($x = 1$) is a function of both the agent's action and the state of nature.

$$\text{prob}(x=1) = p(a, \Theta)$$

The states and effort levels can be ordered so that the probability of a successful outcome is higher for good states and high effort levels, ceteris paribus.

$$p(L, .) < p(H, .), \qquad (1)$$
$$\text{and} \quad p(.,B) < p(.,G).$$

Initially, neither the agent nor the principal knows the true state. All they know is that the prior probability of the good state ($\Theta = G$) is q ($0 < q < 1$). Only the agent knows whether his effort was high or low.

Although high effort is more likely to yield a successful outcome, it comes at a cost to the agent of e, as measured in the agents utiles. Without loss of generality, the cost of low effort can be normalized to zero.

$$c(H) = e, \quad c(L) = 0$$

Finally, we must specify the utility functions of the principal and the agent.

principal: $x - s(x)$

agent: $u(s(x)) - c(a)$, $u' > 0, u'' < 0.$

where $s(x)$ is the share of output going to the agent.

The agent will not agree to any contract that doesn't at least meet his reservation utility of $\underline{u}$. Note that the principal is risk neutral while the agent is risk-averse. This could result if the principal, usually thought of as a firm owner, has more opportunity to diversify her risk in this relationship than does the agent.

We will analyze the case in which effort is sufficiently productive that the benefits of high effort outweigh the costs. regardless of the true state. This allows us to concentrate on the control aspects of the problem insofar as additional information about the state will not change the socially optimal action.

$$e < u[p(H,B) - p(L,B)] \text{ and } e < u[p(H,G) - p(L,G)]. \quad (2)$$

3.3.2 Solutions to the model

If the principal could observe the level of the agent's effort and write a contract on it, the socially optimal solution of high effort could be obtained without requiring the agent to face any risk. Conditional on the agent working hard, the principal would simply pay the agent a flat wage sufficiently high to fully compensate the agent for exerting high effort. The principal would bear all the risk that the outcome might still not be successful.

However, given the fact that the principal cannot know whether the agent has worked hard, she must make it in the agent's interest to do so on his own. The incentive contract can only be conditioned on things that are observable to both the

principal and the agent. In this case only the actual outcome qualifies. Accordingly, the incentive contract must have at most two components and can be written in the form:

$$s(x) = \begin{cases} \alpha + \beta, & \text{if } x = 1 \\ \alpha, & \text{if } x = 0 \end{cases}$$

The agent now risks losing his bonus, β, if it turns out that $x = 0$. If the agent exerts high effort, he can improve the chances that $x = 1$ (from equation (1)) and consequently his expected pay increases. For a high enough value of β, the agent will have sufficient incentive to exert high effort. The principal will seek to keep β to a minimum, however, to avoid exposing the agent to unnecessary risk. Any additional risk the agent faces will require an increase in his average pay (by Jensen's inequality) to compensate him and keep him from falling below his reservation utility. The amount of the base salary, α, will be set so that, taking into account the agent's effort and this risk premium, the expected value of the agent's earnings will not be below his reservation utility. The exact values of α and β that maximize the principal's profits can be derived by solving the following program:

$$\underset{s(x)}{\text{Max}}\ E(x - s(x)).$$

s.t. IR:
$$[(1-q)p(H,B) + qp(H,G)]u(\alpha + \beta) + [1 - [(1-q)p(H,B) + qp(H,G)]]u(\alpha) - e \geq \underline{u}$$

IC:
$$[(1-q)p(H,B) + qp(H,G)]u(\alpha + \beta) + [1 - [(1-q)p(H,B) + qp(H,G)]]u(\alpha) - e \geq [(1-q)p(L,B) + qp(L,G)]u(\alpha + \beta) + [1 - [(1-q)p(L,B) + qp(L,G)]]u(\alpha) \qquad (3)$$

where E(.) is the expectations operator.

Given that high effort is to be induced, this is equivalent to finding the combination of salary and bonus that minimizes expected pay, but still leaves the agent with sufficient incentive to work hard.

$$\min_{\alpha,\beta} E(s(x))$$

s.t. IR: $[(1-q)p(H,B) + qp(H,G)]u(\alpha + \beta) + [1 - [(1-q)p(H,B) + qp(H,G)]]u(\alpha) - e \geq \underline{u}$

IC: $[(1-q)p(H,B) + qp(H,G)]u(\alpha + \beta) + [1 - [(1-q)p(H,B) + qp(H,G)]]u(\alpha) - e \geq [(1-q)p(L,B) + qp(L,G)]u(\alpha + \beta) + [1 - [(1-q)p(L,B) + qp(L,G)]]u(\alpha)$ (3)

At the optimum, both these constraints will be binding. In particular, the optimal value of β, denoted β^*, will be set to equate the expected marginal utility from working to the disutility of effort.

3.3.3 The introduction of an information system

Now consider how the optimal contract changes when the agent (but not the principal) is using a stylized information system. The information system enables the agent to know whether the state of nature is good or bad before deciding what level of effort to exert. One could think of it as a customer profiling system whose use has been delegated to a sales agent; by using the system, the sales agent can determine whether a potential customer is "good-natured" or "bad-natured" before deciding whether to give his pitch.

Although most of the preceding analysis remains unchanged with the introduction of the information system, there is one key change. Because the agent knows what the state is before acting, he can follow a strategy that differs between good states and bad states. As discussed earlier, the improved information has

increased his set of state-contingent options. Because the principal wants the agent to work in both good and bad states, she must now make it incentive compatible for the agent to do so. Before she only had to make working hard in the agent's interest in expectation, generating one incentive compatibility constraint (3). With the information system, the following two IC constraints replace constraint (3).

$$\text{IC(B):} \quad p(H,B)u(\alpha + \beta) + [1 - p(H,B)]u(\alpha) - e > p(L,B)u(\alpha + \beta) + [1 - p(L,B)]u(\alpha)$$

$$\text{IC(G):} \quad p(H,G)u(\alpha + \beta) + [1 - p(H,G)]u(\alpha) - e > p(L,G)u(\alpha + \beta) + [1 - p(L,G)]u(\alpha)$$

Because effort is less productive in the bad state than in the good state, the first constraint, IC(B), will be harder to satisfy than the second constraint, IC(G). This means that higher bonuses will have to be paid to induce effort when the agent knows he is in the low state. However, since the principal does not know what the true state is, she must pay this same higher bonus in the good state as well.[30] Furthermore, because the expectations operator is convex, the constraint IC(B) will also be harder to satisfy than the IC constraint in the previous case (3), when the agent had no information system.

The bonus in the informed agent case is thus higher than the bonus required to motivate the uninformed agent. The additional IC constraints generated by the improvements in the agent's information have made him harder to control.

Note that the agent does not benefit from the higher bonuses required. Since the informed agent will, on average, be getting more pay in the form of bonuses, the principal will lower his base salary somewhat, once again leaving him at his reservation utility.

3.3.4 Extending the model

As the agent's information continues to improve, the proportion of his pay which is performance-based increases monotonically. To see this, consider a progressively better information systems that provide the agent with finer partitions of the state-space. Instead of only identifying 2 states, the agent can identify n distinct states, each of which has a different probability of success given high effort. As the number of distinct states identifiable to the agent increases, the principal must satisfy more and more incentive compatibility constraints. The constraint for the state with the lowest marginal product of effort will be binding and will determine how large a bonus must be paid to assure that, in expectation, the agent still finds it worthwhile to work in that state. To see that the bonus is increasing with better agent information, normalize the agent's utility to zero when no bonus is paid and $u(\beta)$ when the bonus is paid. The bonus is paid whenever the outcome is positive, which, for simplicity, we can assume occurs with probability p_i in state i, if high effort is exerted and probability zero otherwise. Thus, p_i is the marginal product of effort in state i. If we define β^* as the level of bonus required to maintain incentive compatibility in the state with the lowest marginal product of success, we have:

$$u(\beta^*) = e/p_{min}$$

where p_{min} is the marginal product of effort in the "worst" state.

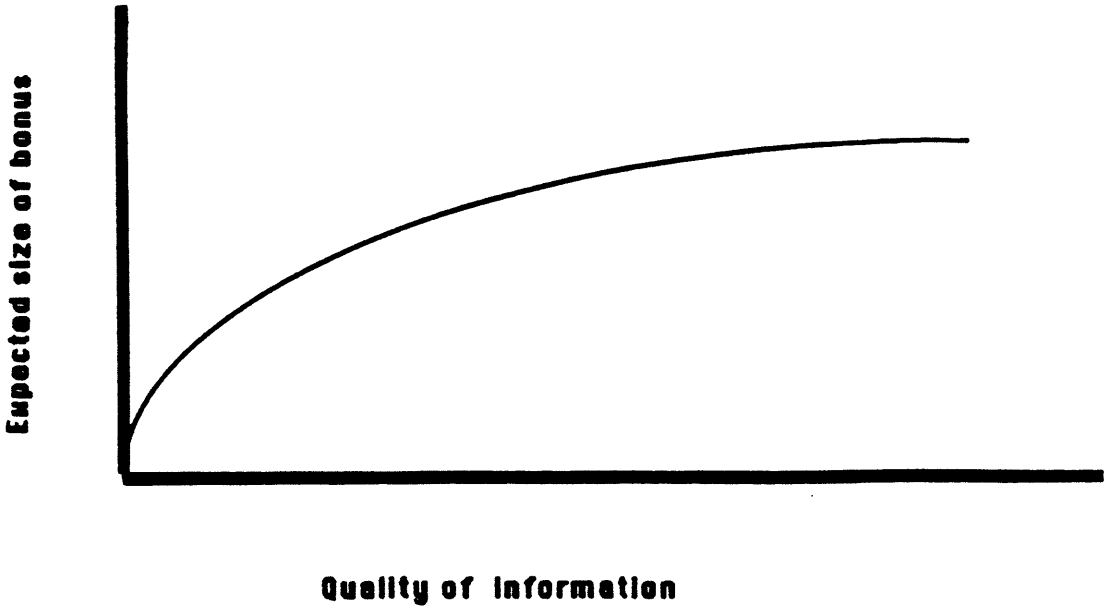
To see that β^* is increasing in the number of states discernable to the agent, note that $u(\cdot)$ is monotonically positive, e is a constant, and the expected value of p_{min} is decreasing in n according to the following relationship:

$$p_{min} = \int pn[1 - F(p)]^{n-1} f(p)\ dp$$

where F(p) and f(p) are the distribution and density of marginal products across states, and n is the number of states discernable.

Figure 3 shows how the bonus increases with better information for the case in which the probability of success is uniformly distributed.

Figure 3: Increase in the agent's bonus as his information improves, uniform distribution case



Welfare is not necessarily enhanced by improvements in information. From the above analysis, one can see that if the productivity of effort in the worst state is sufficiently high, the principal will provide incentives for the agent to exert high effort, regardless of his information. In this case, the information has no effect on production decisions and does not expand the production set in any meaningful way. However, the information does destroy some risk-sharing opportunities; the agent now receives proportionately more output-contingent pay. Thus, in this case, the net effect of better information is to lower welfare.

On the other hand, if productivity in some states is sufficiently low, it will be preferable for the agent not to work in those states, thereby avoiding effort that would have been unnecessarily wasted in the absence of the information system.

The principal can give the agent discretion to choose when and how hard to work and guarantee that the agent will only work in the more productive states by not setting the bonus too high. In a case like this, when the additional information leads to improved production decisions, it is welfare-enhancing. Most real-world cases will be a mixture of the two effects, so we can expect to observe both increases in performance-pay and greater latitude given to the agent in making production decisions.[31]

3.4 The effect of increasing the number of activities

Although the preceding model demonstrated an increase in performance pay associated with improvements in the agent's information, the effect is even more pronounced when the agent must allocate his effort among a number of activities. Information technology can be used by the agent to identify opportunities for increased revenues or reduced costs, but if the agent is paid a fixed salary, he will have no incentive to identify and pursue such new activities. Giving the agent access to such information will require an increase in the output-based component of his compensation, not only to help him identify new opportunities that are valuable to the principal, but just as in the previous case, the information may make performance pay necessary just to keep the agent from using the information against the principal's interests.

Consider a situation similar to the previous case where the agent can apply either high or low effort to an activity, thereby affecting the probability of a successful outcome for the principal. Solving for the optimal contract will yield a share of output paid to the agent, s(x), which will generally be less than 100%.

What happens when the agent is able to identify new ways of generating output, perhaps because of better information or through the introduction of a flexible manufacturing system? Optimally, the principal would like the agent to

engage in a second activity only if the benefits of his effort there outweighed the costs. However, the optimal incentive scheme for one activity is no longer optimal when the agent has the option of engaging in more than one activity. In particular, he will use his new information only when the benefits outweigh the costs to him, personally. Because the agent only gets a share $s(x) < 100\%$ of the total benefits of the new activity, he will ignore it unless the benefits are so large that his share alone will outweigh the personal costs to him.[32] Thus, giving the agent better information about profitable new activities will not be enough to get the agent to act on them unless he has sufficient incentives. In general, the old incentives may or may not be sufficient to also get the agent to work on any given new activity. As the number of new activities increases, it becomes more likely that some profitable ones will be passed up unless the agent's output-based pay is increased.

Furthermore, increased incentive pay may not only be required to keep the agent from forgoing profitable opportunities, but may also be necessary just to maintain the same output levels as before the agent became informed. In fact, any compensation scheme that pays the agent less than a 100% share of output is potentially vulnerable to being undermined when the agent knows about alternative activities which have private benefits to the agent. The agent may prefer to spend his time on an activity which he finds personally beneficial at the expense of the principal's preferred action, since his decisions is based on getting 100% of the private benefits of his actions, but only a share s(x) of the benefits to the principal. The agent will shift effort to a new activity with lower total benefits if it provides greater private benefits, unless the principal raises the his share s(x) sufficiently. As in section 3.3, informed agents are harder to control.

An alternative to increased performance pay is to forbid the agent from engaging in any activities that are not pre-authorized by the principal.[33] Strict rules, fixed job duties, tightly limited budgets and other manifestations of bureaucracy are all examples of limits that a firm can impose on its employees to

reduce the need for incentive pay. However, these measures negate much of the benefit from decentralizing the information processing function to the agent. Furthermore, without extensive monitoring, the principal may not even know exactly which activities the agent is undertaking. As discussed earlier, information work will often be harder to monitor than physical work.

3.5 "Performance pay" isn't always what it seems

It should be stressed that there is an important qualification to the result that performance pay increases as the agent gets better information. This only applies to true performance pay: pay that is linked to output, the whole output and nothing but the output. Often what is called "performance pay" is actually pay linked to indirect performance measures that can only proxy for output.

If the indirect performance measures do not fully reward output in some states, then any information system that identifies these states to the agent will lead to shift effort away from them. As a result, the principal may actually have to reduce her reliance on such indirect "performance-pay" whenever the agent can distinguish among compensated and uncompensated activities. For instance, Holmstrom and Milgrom (1990) show that when the agent has a fixed amount of attention that he can allocate across different activities, it may be necessary to decrease incentives on those activities that can be monitored to keep the agent from reducing effort on the unmonitored activities. Analogous inefficiencies result when "performance pay" rewards all types of productive effort, but also includes rewards for unproductive activities or rewards for actions disproportionate to their value to the principal (Baker, 1990b). Excess effort will be applied to activities that are relatively unproductive but rewarded nonetheless. For these reasons, the benefits of indirect types of performance pay can be ambiguous as the agent gets better information. However, the benefits to providing true output-based compensation will only be strengthened.[34]

3.6 Summary of the role of incentive pay

In summary, as the agent gets better information, the optimal incentive contract will tend to increase the share of compensation that is directly linked to output, while reducing the share that is constant, (e.g. base salary), and, quite possibly, the share that is function of only indirect measures, (e.g. rewards and punishments based on behavior). Rewards based on output, while encouraging more of the right kinds of work, also have drawbacks to the extent that they expose the agent to more risk. However, as analyzed in this section, one cannot capture the full benefits of the agent's improved information without also linking his compensation more closely to output. In fact, improving the agent's information without changing the incentive scheme may well make the principal worse off.

While I have demonstrated in this section a causal link between improvements in the agents' information and increases in the optimal amount of their output-based compensation, this link is strengthened by positive feedback in the other direction. As Baker (1990a) put it:

> The unleashing of middle management creativity which accompanies the use of pay-for-performance compensation systems can be dramatic. When companies alter the terms of employment in such a way that, rather than being told what to do, middle managers are rewarded or punished based on the outcomes of their decisions, these managers have new incentives to learn about their jobs and their environment.

Thus, the use of output-based pay will in turn lead to even better information on the part of agents. This can further reduce the cognitive load on upper managers. Instead of the near omniscience required to direct specific actions, they can be more like the "consultants" and "facilitators" described by Kanter, who help their subordinates by contributing relevant, if not all-encompassing, insights. Instead of commanding, the manager must "sell" his subordinates on the idea that certain actions will likely lead to greater output and, not coincidentally, output-based pay.

Obviously, the shift to output-based compensation systems requires a significant change in the culture and attitudes at all levels of the firm. But information, discretion, and incentives each reinforce each other, and it is difficult to gain the benefits of one without the others.

4. Conclusion

> To remain competitive -- maybe even to survive -- businesses will have to convert themselves into organizations of knowledgeable specialists.
> - Drucker, 1988

4.1 Summary

The shift in the 19th century from a largely agricultural to a largely industrial society was associated with profound changes in the organization of work. The shift now taking place from a largely industrial society to one in which most effort goes into, and most value is produced by, information processing activities may lead to comparable changes in the organizational superstructure.

While the organization of work has begun to change significantly, we are only beginning to understand the nature of those changes. The same characteristics emerge in almost every description of the "new managerial work" in its various incarnations -- decentralization, flexibility, new technologies, incentive pay, reduced hierarchy -- but there has been much less consensus on the underlying causes and mechanisms.

In this paper, I present an agent-theoretic analysis of two features that are at the core of the phenomenon: the decentralization of information and decision-making, and the increased use of output-based compensation. Working within a framework of boundedly rational and self-interested agents, it has been shown that 1) the reduces costs of information can lead to a broader distribution of information work throughout the organization, and 2) as workers become better informed, their

optimal compensation package will include more output-based pay.

The hierarchical, command-based mode of organization is efficient when each manager has no less work-related information than her subordinates do. However, the total amount of potentially useful information about work and the environment has dramatically increased, largely because of advances in information technology.[35] The resulting flood often exceeds the capacity of any one human brain. If the information is to be of benefit to the organization, it must be distributed to multiple agents, along with the decision-making authority to use it. Decision-making agents cannot be managed by prespecifying their actions -- this would amount to deciding for them. The alternative is to change their incentives so that it is in their own interest to maximize the output of the firm. This necessitates the use of output-based compensation. In turn, the output-based compensation system reinforces the agents' incentives to gather more information which, assuming a properly designed incentive systems,[36] can further benefit the firm.

The models present a parsimonious explanation of the causes and mechanisms of the new organization of work, which can be viewed as either a supplement or alternative to previous approaches. Taking seriously the evidence of the organizational field studies also gives insight into the strengths and limitations of applying conventional principal-agent doctrine: while the incentive pay needed to motivate agents with private information is costly, the alternative solution of providing a single principal at the hub of the firm with all the necessary decision-making information is less feasible in practice than theory has suggested. This implies that information economics must be extended to include the costs of human information processing if it is to realistically model complex organizations.

4.2 Managerial Implications

One practical implication of the models presented in this paper is that the

new managerial work of decentralization and output-based compensation is not just a fad destined to go the way of portfolio management. Rather it has a sound economic basis in the increased proportion of information work, enabled, if not required, by the growth of information technology and automation. As their employees become better informed, managers must be prepared to delegate more decision-making and share the rewards of success. In contrast, the all-to-common assumption that advanced information systems will enable tighter control by top management must be tempered by the realization that attention, not information, is usually the scarce resource in the tops of organizations.

Agency theory has long made apparent the importance of collocating decision rights with information, but the models presented in this paper suggest that the new winning organizational strategy is likely to be based on moving decision-rights and incentives out to the field rather than moving more information to the executive suite. This philosophy conflicts with "tried and true" management heuristics that evolved in an earlier environment and may undermine the authority of the traditional chain of command, but the technological and economic forces driving it cannot be ignored. Growing complexity and information overload put an increasing burden on the "visible hand" of management, but at the same time, technology is can provide new opportunities for alternatives to conscious coordination. By distributing the processing load and designing self-regulating systems, tasks beyond the comprehension of any single decision-maker can be successfully undertaken. This paper shows that strengthening the output-based compensation of employees is a natural way to align their incentives to make the right decisions on their own. Instead of directing employees, management can focus on the more manageable task of providing the right rewards for the outputs it desires. In some cases, when output measures are sufficiently refined, even this step can be largely automated with a compensation formula.

The oldest self-regulating system is the market. In fact, management may

want to consider that the ultimate strategy for the decentralization of decision-rights and incentives is the reorganization and dis-integration of the firm itself, thereby providing each division and even each knowledge worker with the full prerogatives and incentives of independent ownership. Because it unavoidably exposes agents to more risk, and given difficulties in decomposing work, the applicability of this strategy may be limited in many industries. Nevertheless, the decline in vertical integration and average firm size (Brynjolfsson, et al. 1989), and the unprecedented increase in number of consultants and entrepreneurs in the past decade (Bureau of Labor Statistics, cited in Wall Street Journal, 1988) may be evidence of its growing success overall.

There are parallel implications for the design of information systems. Technical feasibility notwithstanding, a "master database" is not likely to be successful if its objective is to funnel all the corporate records to the top of the hierarchy, instead of to line personnel. Systems designed for executives will only worsen the bottleneck unless they conserve on managerial attention by providing output that is smaller, and more easily understood than their input. This includes systems like information "refineries" and filters. The most valuable executive systems will not merely retrieve information but will solve some problems autonomously, relieving some (presumably more routine) aspects of the decision-making load. While improved filters and decision-making systems may slow the shift to decentralization, more growth is apt to occur in systems aimed at the emerging needs of the new managerial work. This validates the demand for systems designed to help coordinate large numbers of informed agents within an organization -- such as e-mail, "groupware" and other branches of computer-supported cooperative work -- and systems for coordinating transactions across organizational boundaries, like interorganizational information systems. To the extent that all these are increasingly popular research topics, the models presented in this paper provide some justification apart from their technological merit.

Much of the advice given managers is based, sometimes implicitly, on emulating the practices of successful firms in their industry. The link between the new managerial work and information work derived in this paper suggests other organizations and professions with a historically high proportion of information workers that may serve as models for the emerging structures. For instance, professionals like doctors, lawyers and management consultants, who typically have superior information to the people they work for, are more likely than other workers to have significant discretion and to be paid based on output. Even when they are part of a large organization, like a hospital, they are unlikely to be subject to much hierarchical control. For instance, in most hospitals a triage nurse makes the decision of what case each doctor will handle. While this role is nominally parallel to the management duties in a traditional firm, the perceived hierarchy and authority is very different. Ultimate decision authority and even monetary incentives are more closely aligned with the relative knowledge of the agents than with the nominal flow of work. In light of their common fundamentals regarding the distribution of knowledge, it is not surprising that several researchers have noted similarities between the new organization of work and that of the hospital, consulting firm and investment bank (Drucker, 1988; Eccles, 1988).

The admonitions of management consultants and many academics to imitate these organizations and to decentralize, delegate and provide more incentive pay are supported by the models presented in this paper, but they also suggest that the advice should not be applied wantonly. The new managerial work is best viewed as a rational organizational response to a specific problem, and not as a newly discovered panacea for all that ails business. For instance, the use of incentive pay does not necessarily apply to everyone in the organization but only those whose have the information and knowledge to be properly given decision-making authority. Furthermore, effective use of output-based compensation presumes an ability to measure outputs, which is not always possible. In some cases, when the need for appropriate incentives is particularly acute, firm value, as measured by its stock

price, may be taken as the ultimate output. Unfortunately, stock ownership is an imperfect solution, especially in larger firms, because it subjects the agent to the risk of factors beyond his control.

The manager must also consider his firm's environment and technology before implementing the new managerial work. In stable industries, where the information needed to run the business is minimal, there is little danger of information overload, so the logic of decentralization and performance pay does not apply. Companies that concentrate on only one product, on simple products, and/or on mature markets are more likely to be able to manage their more modest information processing challenges without distributing decision-making.

Finally, the models presented suggest that the new managerial work is in large part a consequence of the strengths and weaknesses of recent generations of information technology: useful information can be generated and distributed far faster than it can be processed. Management would do well to keep an eye on the technology, because there is no guarantee that this will always be the case.

Notes

1. IBM originally estimated the total worldwide market for computers at just 10 units; with the advent of cheap, miniaturized components and microcomputers, over 10 million computers are currently sold annually (Halal, 1986). For a contrary view, arguing that the growing demand for information technology drove subsequent costs declines see Jonscher, (1983).

2. See Crowston and Malone (1988) an excellent summary of the literature on information technology and work organization.

3. Williamson (1975) cites the same two human factors as being at the root of transaction costs. He uses the terms "bounded rationality" and "opportunism". The former limits the "powers of individual to receive, store, retrieve and process information without error" and limits individuals' abilities to "articulate their knowledge or feelings by the use of words, numbers or graphics in ways which permit them to be understood by others". The latter is the "strategic" manipulation of information or misrepresentation of intentions.

4. The strong assumptions, particularly regarding the principal's computational abilities, limit the practical applicability of these results. Holmstrom put it more strongly, saying "the mechanism design approach is not about to deliver an answer to the ultimate question of what an optimal economic system ought to look like." (Holmstrom, 1985)

5. Throughout this paper, by improvements in the quality of information, I mean improvements in the Blackwell sense of greater informativeness resulting from a finer partition of the state-space.

6. He focuses particularly on the LBO partnership.

7. Clippinger and Konsynski call for the development of "information refineries" as a "counter technology, invented to correct the excesses or imbalances of other [information] technologies".

8. We can largely ignore information that is "cospecialized", in that it originates and is used by the same agent.

9. Of course, the organization must still provide incentives for its members to obey these instructions. This issue is taken up in section three.

10. It will only be optimal for more than one agent to process information if they happen to have exactly identical costs.

11. One could speculate that those types of information that lend themselves easily to machine processing because of their concreteness and aggregatibility (e.g. numerical data) would become relatively more centralized by information technology while those

that required extensive complementary processing by humans (heuristic or idiosyncratic pattern recognition) would become more decentralized. Applegate, Cash and Mills (1989) present some evidence supporting this idea; depending on the dimension measured the modern firm is becoming both more centralized and decentralized.

12. Actually, recent trends in the price to performance ratios of computers are increasingly favoring decentralized processing as well. Already, personal computers deliver over 50 times more power, as measured in millions of instructions per second (MIPS) as mainframes (Ferguson, 1990) and small end-user computers are generally predicted to gain an increasing cost advantage over centralized computing (Gurbaxani & Kemerer, 1989). The inability to proportionately scale up the information processing capacity of machines is creating an analogous incentive for decentralizing processing as that discussed in the text with regard to human information processing, and a few researchers are exploring analogous solutions (Huberman, 1988).

13. Simon (1976) has estimated that "we can handle only 50 [bits per second]", and that our short-term memory can store "seven plus or minus two items" (Newell and Simon, 1972). Whatever, the true numbers, human processing capacity is bounded and not easily augmentable.

14. An upper limit on the agency costs is the risk premium that would have to be paid to the agent for him to agree to become the residual claimant on the effects of his actions.

15. For example, decision support systems (Keen and Scott Morton, 1978), knowledge-based expert systems (Hayes-Roth et al., 1983), intelligent information filters (Lai et al., 1989), and information "refineries" (Clippinger and Konsynski, 1989) all seek to relieve aspects of the information processing burden.

16. Malone's (1988) discussion of the "first-order" and "second-order" effects of lower information processing costs is apposite.

17. Van Zandt shows that the lack of an effective price mechanism for "attention" can lead to a loss of welfare for both senders and receivers of information as the cost of communication channels declines. He also provides a brief literature review on attempts to deal with the problem.

18. Agency theory dictates that events which are completely beyond the control of the agent should not enter into the performance contract, unless the agent can affect the consequences of these events on output (Holmstrom, 1979). Baker (1990a) discusses the empirical use of controllable performance measures.

19. The other main branch of the asymmetric information literature is generally called "adverse selection" and studies the affects of differential information before contracts are agreed to.

20. The term "state of nature" is used to refer to any aspect of the environment that could affect the job: customers, prices, suppliers, weather, etc.

21. In my discussion of principal-agent contracts, I will consistently be using the feminine pronouns to refer to the principal and the masculine pronouns for the agent.

22. Ex ante, the optimal effort level can be calculated from the first order condition which equates the marginal costs of effort with the expected marginal benefit of effort, where the expectation is taken over the prior probability of all possible states. Under the typical assumptions of increasing marginal costs of effort and diminishing marginal returns to effort, the second order conditions will be met, although more generally the effort level yielded by this program may not be unique or even globally optimal, unless one puts further restriction on the costs and output functions.

23. More generally, if the principal is not risk-neutral, the optimal contract will still provide for perfect risk-sharing but will provide some insurance for the principal as well. In particular, the ratio of the marginal utility of income to each party will be constant. Formally, in the case where the value of output is x, the share to the agent is s(x), the principal's utility is given by V(x - s(x)) and the agent's utility is separable in his income and his cost of effort, u(s(x) - c(e)), we have:

$$V'(x - s(x))/u'(s(x) = k,$$

where k is a constant determined by how the rents are to be divided between the parties.

24. See Harris and Raviv (1979) for a formal derivation of this result.

25. See for instance Sappington (1983) and Hart and Holmstrom (1987). Obviously, bonuses and/or penalties will lead to suboptimal risk-sharing when the agent is risk-averse and the principal is not. The agent also bears more than the first-best amount of risk when both parties are risk-averse. In contrast to the optimal contract under symmetric information (see note 21 above), the ratio of their marginal utilities will be equal to a constant (as in the first best) plus an additional term that is a function of the observed outcome:

$$V'(x - s(x))/u'(s(x) = k + m(x)$$

26. Myerson (1982) was the first to use the descriptive term "revelation principle", but the technique had been used at least as early as 1973 by Gibbard. Dasgupta, Hammond and Maskin (1979) provide a detailed analysis of the principle.

27. Namely that the space of optimal actions for the agent is at least as fine-grained as the information upon which the actions are based.

28. Baker (1990a) analyzes in depth how making an agents pay contingent on performance measures other than actual output can lead the agent to "game" the performance measure when he has some private information.

29. In some circumstances, meeting the additional constraints will prove so expensive to the principal that she is better off ignoring them, allowing the agent to take sub-optimal actions.

30. In the absence of a public randomizing device to convexify the payoffs, the revelation principle does not apply. However, introducing convex payoffs and applying the principle would not qualitatively change the results anyway.

31. It is usually, but not always, advantageous to give the agent greater discretion as his information improves. Holmstrom (1984) shows that in a quantity-control model drawn from Weitzman (1974) the agent will have fewer restrictions on the quantity of a good he provides but found that his results could not be directly generalized.

32. Recall that because the agent's effort is unobservable to the principal, she cannot compensate him for directly for his effort.

33. Holmstrom and Milgrom (1990) discuss extensively how curtailing the agents options can reduce the need for incentive pay.

34. Changes in the value of the firm are the ultimate measures of the contribution of an agent. When no other good performance measures exist or contracts are otherwise incomplete, giving the agent partial, or even complete, ownership of the firm may be necessary. This topic is explored further in Brynjolfsson (1990).

35. A natural extension of this paper would be to consider other factors that have increased the amount of information work done like education, training and experience, and determine whether these have had similar effects on the organization of work.

36. Of course, to the extent that many incentive systems do not fully align the agent's goals with those of the firm, they will lead the agent to gather too much of the wrong kinds of information.

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