Firm Structure, Search and Environmental Complexity

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Abstract

In this paper we explore the information processing problem of the firm by modeling the firm as type of network, which is comprised of two kinds of agents, 'searchers' and 'managers.' The searchers explore the external environment and report the information to the managers. We study the role of centralization/decentralization in organizational structure to see how it affects performance of a firm. Centralization is defined in terms of the level at which decisions are made. We assume the information processing organization is arranged hierarchically, but that decisions can be made at different levels, and thus centralization directly relates to the quantity of information used in making a decision. We model the external environment as an NK landscape. Via simulations, we explore which type of organizational structure and level of decision making maximizes firm profits, given the complexity of the environment.

1 Introduction

The problem of information processing for the firm has only recently begun to attract attention by economists. In general, the firm faces more information than can be processed by one individual. As a result, the firm has agents that specialize in particular tasks: some agents are devoted to production, others to sales and marketing, and finally others whose sole job is simply to process information and make decisions ('managers') (Radner, 1992).

In this paper, we explore the information processing problem of the firm by modeling the firm as a network of information processing nodes. The network is comprised of two kinds of agents, 'searchers' and 'managers.' The searchers explore the external environment and report their information to the managers. We explore the role of centralization versus decentralization in organizational structure to see how it affects firm performance.

Our main research question is: Given the complexity of the environment, which organizational structure and level of decision making authority optimizes firm performance. Here we define centralization in terms of the level at which decisions are made. We assume the information processing organization is arranged hierarchically, but that decisions can be made at different levels. Thus centralization directly relates to the quantity of information used in making a decision about the firm's activities. A highly decentralized firm has decisions being made at the lowest level of the hierarchy and with agents having the least amount of information; a highly centralized firm has decisions being made at the top of the hierarchy, where the top agent ("CEO") has full information about the payoffs to potential activities. We explore the effect of centralization on performance for different types of environments.

We model the external environment as an NK Landscape (Kauffman, 1993), which has, in recent years, been increasingly used as a convenient way to model a complex environment, where components of the environment are intertwined, and small changes in the environment can have nonlinear effects on payoffs. In this paper, we model the firm as a directed graph of information processors that tries to locate the highest payoff in the environment.

We find that in simple environments, the benefits of decentralization outweighs the costs; thus decisions made at the local level are better since there is little gained by amalgamating information at the higher levels, and the firm can process information faster. As the degree of modularity in the environment decreases, a centralized organization becomes more efficient because having the 'big picture' outweighs the increased delay in processing information. Furthermore, as we increase the degree to which projects are interrelated, we also show a similar increase in the benefits of centralization.

1.1 Related Literature

Information Processing Organizations Our works fits within the crossroads of economics and management, and within the crossroads of the economics of information processing organizations and the study of complex landscapes. In regards to information processing and organizational structure our paper relates to the following works. Radner (1992, 1993) models the firm as a type of problem solving machine. Each agent must perform an associative operation (e.g., adding numbers, or finding the maximum number), and pass the output to another agent in the network. Given his particular machine, Radner finds that the most efficient network, in terms of minimizing the cost of processing information, is hierarchical in nature (i.e., a tree graph). Since the problems to be solved can easily be decomposed and are fixed, there is no issue of the role of search in processing information or any role of environmental complexity. Furthermore, Radner's model requires great simplification of the firm's task in order to yield analytic results.

Barr and Saraceno (2002) model the firm as a type of neural network whose objective is to learn the external environment. The neural network is a particular type of organizational structure (graph) that is capable of learning a data set. They demonstrate the relationship between environmental complexity and firm performance, but they do not focus on the decentralization of decision making, only the decentralization of information processing.

In Miller's (2001) model, organizations are comprised of randomly generated networks of agents that perform associative operations. Over time organizations evolve by using genetic algorithm type rules to mutate or combine suborganizations in order to improve their speed of computation.

The work of Rivkin and Siggelkow (2003) is closely aligned with ours. In their model, the organization is comprised of a CEO and two subordinate managers, with decision making control for a department or firm unit. Firms differ in the decision making role of the CEO, the quantity of information received from the subordinates, and agents' incentives regarding consideration of other agents' information. Furthermore, the decision set is modeled as an NK landscape.

This paper is similar to ours in two respects. First, they consider a type of 'overlay' of an information processing organization over a rugged landscape. That is to say, a network of information processing agents search the landscape and make decisions about which locations return satisfactory payoffs. In addition, they consider the role of centralization versus decentralization of decision making. In their model either the CEO can make decisions or the subordinates can.

However, our model differs in a few respects. First, we do not limit the size of the organization to just three agents. While we do assume a hierarchy for the information processing network, we consider organizations of different sizes and different distributions of agents among the layers of the hierarchy. In addition, similar to Radner (1992; 1993), but unlike Rivkin and Siggelkow (2003), we explicitly consider the costs to the organization for processing and information and search. Their model uses a quite small landscape (of only 6 bits) and thus considering the cost of search becomes relatively less important. In our model, we work with a landscape with many possible configurations (100 bits or 2^{100} different configurations) and thus the nature of the search process becomes an important determinant of costs. In our paper, we do not address incentives.

Complex Landscapes In recent years, economists have begun to search for modeling tools that incorporate complex environments. The standard models of the firm tend to introduce environmental complexity by adding a stochastic component to a production or cost function (Jovanovic, 1982; Pakes and Ericson, 1998), thus the learning and searching problem becomes one of discovering population moments related to costs or inputs. However, these models do not address the complex, interrelated components of the economic environment that tend to interact in a nonlinear way. For example, the choice of production technology for the firm can have implications for the production process in general, how the product is marketed, what types of inventories to have, and whether to branch out to related products or not (Lawrence and Lorsch, 1986). Furthermore, production technology choice often involves indirect effects associated with network externalities and product lock-in (David, 1985) Thus, the production process is a complex set of interrelated activities, and a change in one activity can have implication for the performance of other parts of the firm.

In this vein, economists have tried to model and understand these complex systems with the use of NK Landscapes. Developed for the study of biological systems (Kauffman, 1993), these models have natural implications for complex economic systems such as the internal working of the firm and the nature of technological innovation.

Auerswald et al. (2000) model the mapping between technology choice and labor costs as a landscape. They then investigate the process of learning by doing, by having firms search among different technology choices. They are able to generate various learning curves based on different parameters. In a related paper, Kauffman, et al. (2000), also model the environment as technological recipes. In this paper, the authors investigate the question of how 'far' should a firm search to find a more productive recipe. Search is given by the number of procedures that are changed at a given time. They find that early in the search process it is optimal to search relatively far, but as the firm improves its production methods search should become more localized.

Chang and Harrington (CH) (2000; 2001; 2003) have a series of papers that model the adaptive search process of organizations. In their basic model, the rugged landscape represents the space of retail store practices. In CH (2000), for example, the authors consider the issue of centralization versus decentralization in the implementation of new store practices (i.e., whether individual store manager or HQ controls the dimensions of organizational change). In CH (2003), the model is extended to include competition among retail chains.

Papers by Levinthal and his coauthors explore organizational performance on rugged landscapes (Levinthal 2000; Levinthal and Warglien, 1999; Gavetti and Levinthal, 1999). For example, Gavetti and Levinthal (1999), model the bounded rationality of firm managers, by having them make decisions based only on a subset of the N elements that comprise the landscape.

The rest of the paper is as follows. Section 2 presents the model of the environment as an NK Landscape. Next, section 3 discusses our model of the information processing organization. Then, in section 4, we present our simulation results. Finally, section 5 gives some concluding remarks.

2 The Environment

We model the environment as an NK Landscape (Kauffman, 1993), which is a useful way to depict environmental conditions facing the firm. In regards to the 'environment,' though, the demarcation between the purely external environment and the purely internal environment is often fuzzy.[1] There are many items strictly outside the firm's control that directly affect its profitability, such as input prices (and related shocks), interest rates, rival entry, technological innovation, etc. However, we can also speak about the internal environment of a firm, such as the many technological and organizational components that it can control, including how it organizes its various activities such as production, marketing, research and development, distribution, etc. The reason that the external and internal environments cannot be completely separated is because the organization of the firm and its ability to successfully carry out its mission is based on its on-going adaptation of its practices to the particular technological and competitive environment (Lawrence and Lorsch, 1986).

The literature on organizations (Simon, 1997; Cryet and March, 1963) and organizational design (Lawrence and Lorsch, 1985; Miller and Friesen, 1984) show that there are a few salient facts about the firm and its environment that make the internal nature of the firm relevant for economic analysis: (1) There are many variables that determine the performance of the firm; (2) these variables often relate in a complex, nonlinear way; (3) the discovery of how these variables relate and how they affect firm performance is an immensely complex job, which requires a relatively large number of agents, whose main objective is to search for information, process it and make decisions; (4) information processing and decision making also require that the firm processes information in as efficient manner as possible, and this manner itself will be a function of the nature and complexity of the information; and (5) the ideal situation of profit maximization is often prohibitively expensive due to the necessary computational resources needed to discover optimal decisions.

The NK Landscape is a convenient way to model the firm's environment because of the nonlinear structure of the landscape and the ability to 'fine-tune' the complexity level of the landscape. As will be discussed in more detail below, the landscape is a large space over which

[1] There is a separate line of research that investigates the boundaries of the firm from the point of view of property rights and asset ownsership. See Holstrom and Roberts (1998) for example.

the firm must search. In general, the objective of the firm is to locate the highest possible payoff subject to the costs of search and given its information processing organization.

In this paper, we have two measures of complexity: one is how tightly coupled the environmental system is (K); and controlling for this, the other is a measure of how the couplings are ordered (β). β, when K is small relative to N, is a measure of modularity of the environment (Langlois, 2002). A complex system is not necessarily an ordered system in the sense that it is often not clear how the parts are linked, and how they affect the performance of the firm or complex systems in general; β is a convenient way to capture this phenomena.

Landscape search procedures have been modelled in different ways, including simulated annealing and local hill climbing. Our method of search is slightly different than these methods because we are interested in investigating the role that IP organizations play in the nature of search. We assume that there are agents who search locally, but that they only observe a particular subset of all possible projects. These these agents report their information to others who then assemble and process it. The idea motivating this is that the landscape is a large space that requires several agents to search it; and that the possible gains from multi-agent search outweigh the costs of computation.

2.1 Payoffs

The landscape is a mapping from the set $\mathbf{X} = \{0,1\}^N$ to R_+. That is to say, an element from the environment $\mathbf{x} \in \mathbf{X}$ is a vector of binary digits of length N, and each $\mathbf{x}$ is associated with a payoff $\pi(\mathbf{x}) \in R_+$. How this mapping occurs also depends upon the value of K, which is a parameter that specifies the degree of interaction among the elements of $\mathbf{x}$. Thus K is an important measure of environmental complexity. A high value of K means that elements of $\mathbf{x}$ are highly interdependent; a change of one value of $\mathbf{x}$ can cause dramatic changes in the payoffs associated with the new vector $\mathbf{x}'$. In the simplest case, when $K = 0$, there are no interdependencies, and, as a result, a change in $\mathbf{x}$ of one bit will result in a relatively smooth change in payoffs.

Assigning payoffs works as follows. In the $K = 0$ case, the value of each bit is independent of the value of the other bits for a particular $\mathbf{x}$. Thus we create the 'landscape' as follows: for each bit $x_i, i = 1, ..., N$ we assign a payoff $\pi_i(x_i)$ that is a randomly generated number from a uniform $0-1$ distribution. So for example if $x_i = 0$, it assigned a particular randomly generated number, and if $x_i = 1$ it is assigned another randomly generated number. In this case then we generate $2N$ different random payoff values. The value of each $\mathbf{x}$ is given by

$$\pi(\mathbf{x}) = \frac{1}{N} \sum_{i=1}^{N} \pi_i(x_i), \tag{1}$$

the average of the payoffs for each bit.

In the case of $K = 1$, the payoff of each bit x_i is also determined by the value of a bit x_j, $i \neq j$. Thus for each possible value of x_i and x_j we randomly generate a payoff value $\pi_i(x_i; x_j)$. (We discuss the relative locations of x_i and x_j below.) Since the payoff of x_i depends on the value of x_j, we have four possible payoffs associated with x_i, one when $x_i = 0$ and $x_j = 0$, one when $x_i = 1$ and $x_j = 0$, and so on. Thus to create a landscape, we generate $4N$ payoffs. The payoff of any particular vector is given by

$$\pi(\mathbf{x}) = \frac{1}{N} \sum_{i=1}^{N} \pi_i(x_i; x_j). \tag{2}$$

In the general case for any value of K, we have payoffs of x_i determined by the value of K other elements:

$$\pi(\mathbf{x}) = \frac{1}{N} \sum_{i=1}^{N} \pi_i\left(x_i; x_j^1, ..., x_j^k\right), i \neq j$$

To create a landscape we randomly generate $2^{k+1}N$ payoff values.

2.1.1 Interdependencies

As we said above, K measures the degree to which bit payoffs are interdependent, but we did not describe which elements affect which ones. To generate a graph of connections, we introduce the parameter $\beta \in [0, 1]$, which controls the degree to which the environment is locally coupled. The structure of interdependencies are created as follows. We begin by assuming that for a given K, the bits that affect each x_i (x_i's 'neighbors') are the K nearest ones. For example, for $K = 2$, the payoff associated with x_i is determined by the bit values of x_{i-1} and x_{i+1}. The vector is considered circular in the sense that the payoff to the left-most elements are affect by the value of the right-most neighbors. The neighbors of x_N are x_{N-1} and x_1.[2] Then, with probability β, each connection between x_i and its neighbor is broken and replaced with a connection to a randomly chosen bit. Thus, when $\beta = 0$, the 'neighbors' of x_i remain to be its K nearest bits. When $\beta = 0.5$, on average, half of the connections are replaced with randomly chosen bits. And when $\beta = 1$, all the connections are randomly rewired. See Fig. 1 for an example.[3]

While the parameter K governs the nonlinearity of the landscape, the parameter β governs localness of interdependencies, although these two are not completely independent. For example, when $K = 0$ (environment is fully unconnected), β is irrelevant. It is also the case that when $K = N - 1$ (environment is fully coupled), β is irrelevant. The interesting cases are when K is relatively small compared to N. In that case, the parameter β, which governs the localness of interdependencies, can also be interpreted as the degree to which the

[2]In the case where K is odd, we have the extra neighbor residing on the right side of x_i.

[3]This way of spanning between ordered ($\beta = 0$) and random ($\beta = 1$) structure was proposed by Watts and Strogatz (1998). They found that in between the two extremes, there exists "small world" structure – structures with a high local clustering and a low path length – that can be observed in varieties of setting from social interactions such as structure of friendships and co-authorship to more technological ones such as internet and electricity grids.

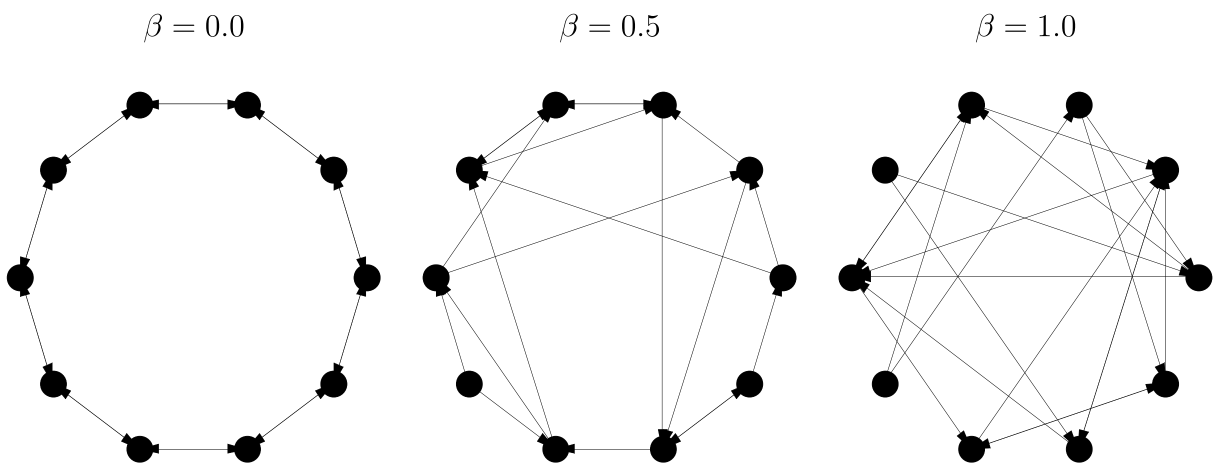

Figure 1: Example of connectedness among bits of the landscapes for three values of β: $\beta = 0$ (left), $\beta = 0.5$ (center), and $\beta = 1.0$ (right). $N = 10$ and $K = 2$.

landscape can be modularized. The modularity of the landscape plays an important role in determining the performance of the organization because, as we discuss in the next section, we assume that an organization divide up the vector of size N into consecutive subvectors of smaller sizes, and assign them to subcomponents of the organization.

As we discuss in the next section,

3 The Organization

In this paper, we model the organization as a type of directed graph. There are two types of agents, 'searchers' and 'managers.' Searchers are associated with a particular location on the NK landscape. They search and report the location to the managers, who then transmit information up the network to the final or terminal node (the "CEO"). An important parameter for the organization, apart from those determine its structure, is the locus of decision making authority, which will be discussed below following a description of organizational structure and the role of searchers.

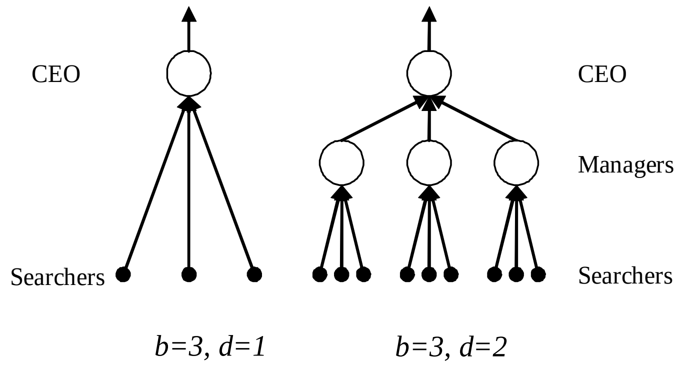

Figure 2: Two types of organizational structures

The Organizational Structure The general organizational structure is given as a directed graph, where information flows from the field agents to the managers and to a final node ('CEO'). We generate organizations based on two parameters, $b \geq 1$ and $d \geq 1$. The value of b, the "branching ratio," is the number of subordinates per node. "The depth," d, is the number of vertical layers. The size of an organization, including 'CEO', with branching ratio b and depth d is $\sum_{j=0}^{d} b^j$ where b^d of them are searchers.[4] Two examples of organizations are given in Fig. 2.

The organization divides up the landscape as follows. First each of the b managers are given 'control' over the greatest integer number of bits less than N/b (i.e., each managers is assigned $\lfloor N/b \rfloor$ bits). If $b \lfloor N/b \rfloor \neq N$ then each manager is assigned additional bits in turn, until the landscape is fully partitioned. Given that each manager has b subordinates, the set of bits assigned to a manager is further divided up into smaller sets, and assigned to his subordinates in a similar manner as described for the managers. Therefore, the landscape of size N is fully partitioned among the searchers.

[4]This way of generating organizations is rather limited in the sense that it does not generate all the possible structures for a given organizational size, a point we would like to address in future versions of the paper.

The Searchers Let's say we have S searchers. For a given landscape of size N, we partition the searchers (also referred to as 'field agents') so that each searcher evaluates a particular subvector of $\mathbf{x}$ such that at a given time agent s evaluates ω_s bits. Mathematically, we refer to the bits under agent s's consideration as χ_s, such that $\cup_{s=1}^{S}\chi_s = \mathbf{x}$ and $\cap_{s=1}^{S}\chi_s = \emptyset$; we call a particular χ_s at a given time as agent *$s's$ proposal*.

Each period each field agents flip a randomly chosen bit under her control. If the searcher has decision making authority, she calculates the payoff of the new proposal, which is the average payoff of the payoffs of the bits under her control:

$$\pi_s\left(\chi_s\right) = \frac{1}{\omega_s}\sum_{i\in\chi_s}\pi_s\left(x_i\right). \tag{3}$$

Notice that the searcher only observes a payoff for each bit, but they does not have any knowledge about how the bits are interconnected. If the change improves her payoff (calculated by using equation 3) she proposes that change. If not, she proposes the status quo. If she does not have decision making authority she simply passes the proposal up to her manager.

Authority and Decision Making Another important parameter is $a \in \{0, ..., d\}$, the "authority level," which gives the layer at which the final decision are made. The level of authority determines how centralized the decision making is. If $a = 0$, the authority is given to the highest level, i.e., to the 'CEO', thus the organization is *fully centralized*; in the case of $a = d$ decisions are made by the searchers themselves, and the organization is *fully decentralized*; for $0 < a < d$ decisions are made by the middle managers if they exist.

In the fully decentralized case, each period a searcher randomly flips one of the ω_s bits under her control and evaluates the payoff according to equation (3). Then she compares it to the previous proposal. If the new payoff is greater than the current one, she selects the new one. If not, she keeps the current proposal. Next she passes the proposal (i.e., the subvector) up the hierarchy to the next level. The manager above the searcher then takes the proposal fed to him and ”joins” it with proposals from the other searchers under him. Notice that when authority resides in the lowest level, the agents above the decision makers only act as information processors – joining the proposals and passing them up the hierarchy to the CEO, who then calculates the final payoff for the entire proposal.

If the authority resides with the middle managers then the decision making works as follows. Each searcher randomly flips one of the ω_s bits under his control and evaluate the payoff as above. The field agent passes the new proposal, if any, up to the manager above her. Each manager 'takes in' the proposal from his subordinates and compares the proposals one by one holding everything else constant. For example, if a manager has 3 subordinates, and all the subordinates has posted new proposal, first he evaluates the new proposal of subordinate 1, while keeping the subvectors assigned to subordinate 2 and 3 to the old ones. Next, he evaluates the new proposal of subordinate 2, keeping the subvectors assigned to subordinate 1 and 3 to the old ones, and so on. Thus if each manager has b subordinates, then each manager only evaluates at most b new proposals, and passes the best one up in the hierarchy to the CEO, who joins the b proposals from the managers and calculates the final payoff.[5]

The similar procedure is applied when the authority rests with the CEO. Now the middle managers, if they exist, act as screeners, comparing the b proposals offered to them by their subordinates. Then they pass up the best one to the CEO. The CEO evaluates the b new proposals from his subordinates and selects the best one.

Notice that the higher is the authority level, the more information is used to make a

[5]Note that each manager evaluates at most b new proposals, and then takes the maximum value of the $b+1$ proposals (the b new ones and the old/current one). The assumption about managers evaluating one proposal at time and choosing the best one, instead of considering all the possible combination of received proposals, is made for simplicity. In the future version of the paper, we are planning to consider higher capabilities of managers by allowing them to consider all the possible combinations.

decision. This becomes particularly relevant as we increase K and β, since, *cet. par.,* an increased value of K means more interdependencies among the environmental bits, and greater centralization confers a greater ability to evaluate all the proposals; similarly, increasing β decreases the localness of the interdependencies, and a 'big picture' view of the projects is required.

Organizational Costs While there are several costs involved with carrying an organization and processing information, here we just focus on a particularly important cost associated with our model. Namely, the level of decision making authority directly affects the speed of search. In short, for a given organizational value of b and d, if we change a, we change the amount of searches the field agents can do in a specified period of time. So, for example, when $d = 2$ and $a = 2$, field agents have decision making authority. In this case, each field agent compares a new proposal to an old one and makes a decision. She then passes up the chosen proposal to her managers and continues to search. We assume for simplicity that there are no 'bottleneck' costs, i.e., we assume managers can finish their tasks before new information arrives from the searchers.

If the managers have the authority, then after a field agent sends up a proposal, she has to wait for the manager to evaluate b proposals from all the subordinates and choose the best one before she can search again. Thus, the field agent is essentially idle for a time proportional to b. If the CEO has decision making authority, then the searchers must wait until both the managers and the CEO make a decision, which increases the idle time even more. In the simulations below, we demonstrate the nature of the tradeoff between the speed of search due to local decision making and having more information. Given different environments, there will be an organizational structure that balances these tradeoffs.

3.1 An Example

Here we give three examples to make the information processing and decision making more concrete. Take the basic structure as follows. Say $N = 8$, and the initial proposal is

$$x_0 = \{\underbrace{\underbrace{\underbrace{00}_{s_1}\,\underbrace{00}_{s_2}}_{m_1}\,\underbrace{\underbrace{00}_{s_3}\,\underbrace{00}_{s_4}}_{m_2}}_{CEO}\}.$$

Further assume the organizational structure is $b = 2$ and $d = 2$ (i.e., two subordinates per node; three layers including 'CEO'). Each manager is assigned to a particular 'location' of four bits. For example, manager one (m_1) is assigned to the first four, which is further divided into two 'locations' of two bits that are then assigned to his subordinate – searcher one and two (s_1 and s_2).

Scenario 1: Searchers have authority ($a = 2$). To begin, each searcher randomly changes one bit. Lets say s_1 gets $\{01\}$, s_2 gets $\{10\}$, s_3 gets $\{01\}$ and s_4 gets $\{10\}$. Since the authority level rests with the searchers, all the nodes above them simply transmit information. In this case the project selection mechanism works as follows: each searcher compares the payoff of the new proposal to the old one (which is done by taking the average of the payoffs of the bits under his/her consideration). So for example, s_1 compares $\pi_1(00)$ to $\pi_1(01)$; whichever is greater gets selected as the current proposal. Let's say for all the searchers the new locations are better. Then the current proposal selected for the firm would become $\{01\,10\,01\,10\}$ with associated payoff of $\pi(01\,10\,01\,10)$.

Scenario 2: Managers have authority ($a = 1$) As above, let's say the initial proposal is $\{00\,00\,00\,00\}$. Again, similar to above, each searcher randomly flips one bit, and let's assume these flips and payoff calculation by searchers yield the same outcomes as before: s_1 proposes $\{01\}$, while s_2, s_3, and s_4 propose $\{10\}$, $\{01\}$, and $\{10\}$, respectively. Since the managers have authority, the searchers pass the new proposals up to the managers to make a decision. Thus manager one (m_1) considers the payoffs to three subproposals: $\{00\,00\}$, $\{01\,00\}$, and $\{00\,01\}$. Notice that the manager looks at new proposals that have only one bit changes.

Again, assuming s_3 and s_4 propose the same proposals as above, m_2 evaluates three subproposals $\{00\,00\}$, $\{01\,00\}$ and $\{00\,10\}$. Let's say, for example, that m_1 finds $\{01\,00\}$ to have the highest payoff and m_2 finds that $\{00\,10\}$ is the best, then the CEO receives the total proposal of $\{01\,00\,00\,10\}$, which becomes the current proposal of the firm, for a payoff of $\pi\,(01\,00\,00\,10)$.

Scenario 3: CEO has authority ($a = 0$) Once more, let's assume all the initial conditions and picks of the searchers are as above. In this case, the managers act as a first set of screeners. m_1 considers as before $\{00\,00\}$, $\{01\,00\}$, and $\{00\,01\}$, and m_2 considers $\{00\,00\}$, $\{01\,00\}$ and $\{00\,10\}$. Say, as above, each selects $\{01\,00\}$ and $\{00\,10\}$, respectively. Now the CEO's job is to consider the three proposals $\{00\,00\,00\,00\}$, $\{01\,00\,00\,00\}$, and $\{00\,00\,00\,10\}$ to select the best one. Suppose $\{00\,00\,00\,10\}$ has the highest payoff; it then becomes the current proposal.

In conclusion, notice that their is a tradeoff between the number of bits changed and the level of centralization. Centralization allows the CEO to view the 'big picture' but at the cost of relatively more local searches. This tradeoff becomes an issue when we look at different environmental complexity levels.

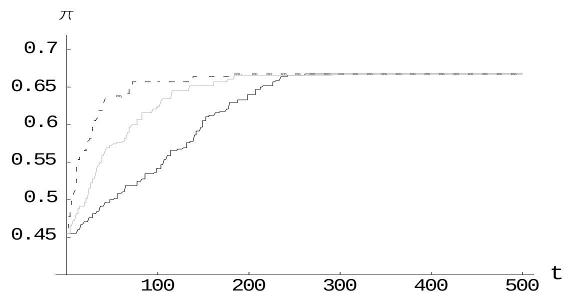

Figure 3: $K = 0$,$b = 2, d = 2$. Dashed Black: authority at level 2 (at the bottom) Gray: authority at level 1 (middle) Solid Black: authority at level 0 (at the top)

4 The Simulations

The model has a total of six parameters: three of them, $\{N, K, \beta\}$, determine the environment an organization faces; the other three, $\{b, d, a\}$, determine the internal structure of organization. The main question we ask is: Given a particular environment, which organizations have the best performance given the environmental complexity?

First, we consider organizations with $d = 2$, (i.e., one management layer, a CEO, and the layer of searchers), and we vary the number of subordinates per manager. To run the simulations, we fix $N = 100$, then for each $K \in \{0, 2, 4, ..., 10\}$, $a \in \{0, 1, 2\}$ and $\beta \in \{0, 0.2, 0.4, ..., 1\}$ we begin by placing the searchers on randomly selected locations on the landscape. Next, the organization searches and processes information, as described above in section 3, for a total of 500 periods. For each set of parameter values, we repeat the search process 100 times and take averages.

First we present some graphs that demonstrate typical cases. Figure 3 shows the time series for the case $b = 2$, $d = 2$, and $K = 0$. Note that when $K = 0$, β is irrelevant since the environment is fully unconnected. Here the organization with completely decentralized decision making (shown in dashed black) finds the global peak much faster than others, and thus it obtains higher per period average payoff than others. The reason is that the field agents do not have to wait for their proposal to be evaluated by the managers. In fact the lower the level of decision making, the faster the search. Simply put, in a very simple environment, there is nothing gained by evaluating information at higher levels. Thus faster search by the field agents is better, even though all three organizations eventually locate the highest payoff.

Figure 4 shows outcomes for $K = 8$, $b = 2$, $d = 2$ and two values of β: $\beta = 0.4$ in the left and $\beta = 1.0$ in the right. When $\beta = 0.4$, we see that an organization with authority in the middle (shown in gray) finds a higher peak than the one with centralized decision making (shown in solid black). Unlike the case with $K = 0$, where there is an unique peak in the landscape, when $K = 8$ there are many local peaks with varying levels of payoffs. In such an environment, an organization with completely centralized decision making can easily be stuck in one of many local peaks where the payoff need not be the highest in the entire landscape. On the other hand, organizations with decentralized decision making can avoid being trapped in such a local peak with lower payoff. This is because the position of a decentralized organization in the landscape can change if such a change is beneficial for one of the components of the organization, even when such a shift results in lower payoff, at least temporarily, for the organization as a whole. This illustrates that there are situations where possibilities of disagreement within an organization can be beneficial, precisely, because such disagreement can allow an organization that has found a locally best practice (at the local peak of the landscape) to experiment with new things and find better practice than the current one. Too much decentralization, however, can be harmful as we can see from the payoff for the organization with completely decentralized decision making. Such organizations fail to find and stay at even a local peak in a complex environment, and their payoffs demonstrate high volatility.

The benefit of moderate decentralization, however, disappears when the environment is much more complex, as we can see in the right panel of the Fig. 4. When $\beta = 1.0$,

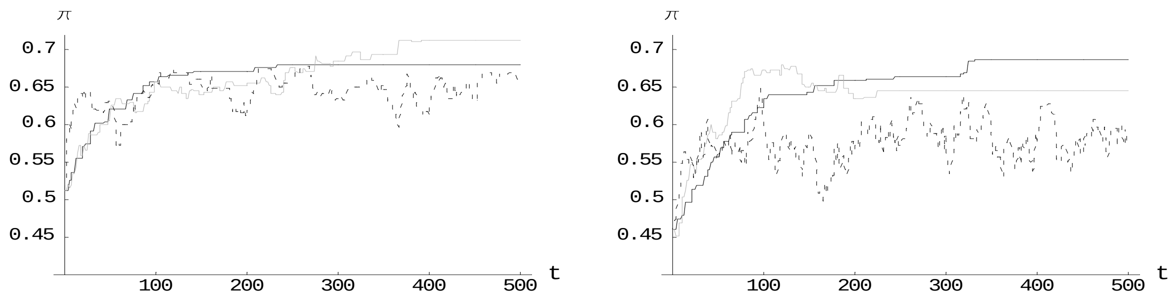

Figure 4: $K = 8$,$b = 2, d = 2$, $\beta = 0.4$ (left) and $\beta = 1.0$ (right). Dashed Black: authority at level 2 (at the bottom) Gray: authority at level 1 (middle) Solid Black: authority at level 0 (at the top)

the most centralized organization performs the best. When the tasks of organizations is difficult to modularize, as is the case when $\beta = 1.0$ because environment are coupled globally, decentralization simply does not function. This point can be better observed in Fig. 5, which demonstrates the relationship between organizational performance and β for different values of K. We see that increasing β is associated with a general decrease in performance, but the effect is stronger in a complex environment (here in terms of higher K) and for decentralized organizations. For example, the top right panel of Fig. 5 shows that when $K = 8$ we see that for $\beta = 0$ the decentralized organization is best; but as β increases, its relative performance deteriorates.

This finding is replicated for a larger organization as well (see bottom 2 panels of Fig. 5 for organizations with $b = 5$ and $d = 2$). It should also be noted that when an organization is large and the environment is highly coupled (high K), as in the bottom right panel of Fig. 5, the completely decentralized organization ceases to outperform more centralized organization, even when β is very low. This is because for a given value of $K > 0$, the larger the organization, the higher is the interdependencies among field agents, even when β is zero. For example, there are 25 fields agents in an organization with $b = 5$ and $d = 2$. Since these 25 fields agents are dividing up the landscape with $N = 100$, each field agent is responsible

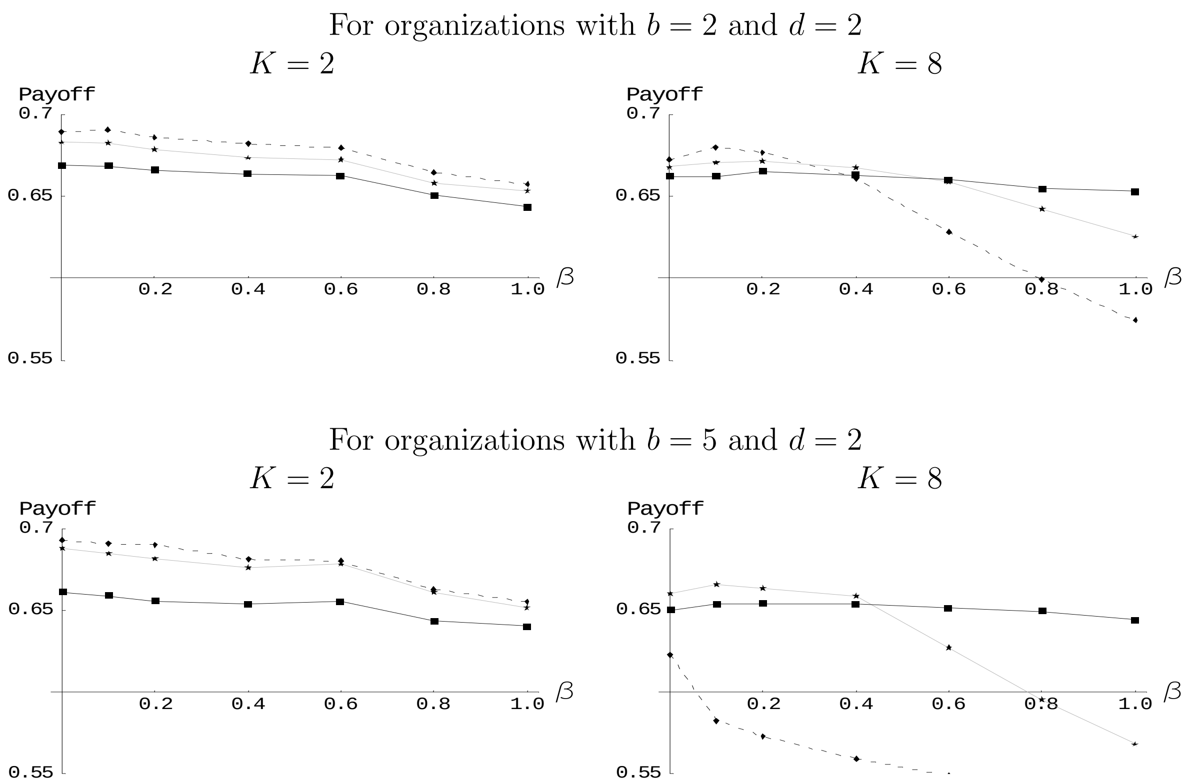

Figure 5: Organizational performance as a function of β for differing authority levels and K. Dashed Black: authority at level 2 (at the bottom) Gray: authority at level 1 (middle) Solid Black: authority at level 0 (at the top)

for 4 consecutive bits. Thus when $K = 8$, even at the lowest value of $\beta(= 0)$, an action of one field agent always affects the payoff of at least 2 neighboring agents. Since field agents do not consider how their decisions affect the payoff of the others, the organization fails to find even a local maximum in such case, just as a small organization with decentralized decision making failed to do so in the more globally coupled landscape.

5 Conclusion

In this paper we have presented a model of an information processing organization. The firm is modeled as a hierarchical network (tree) of two types of agents: searchers and managers. The searchers seek out new projects for the firm to evaluate, and managers process this new information. We also study the degree to which centralization/decentralization plays a role in firm performance.

We measure the environment as an NK Landscape, which is a mapping from firm decisions about projects to payoff values. We fine-tune the complexity level of the environment with two parameters, K and β. K is a measure of the degree to which projects are interrelated, and thus is a measure of the degree to which a change in one project affects the payoff of the firm. Low K values mean relatively smooth changes in payoffs with small changes in projects, and high values of K means a relatively large change in payoffs with small changes in projects. β relates to how these projects are coupled. When $\beta = 0$, projects are connected locally, thus provided that K is not too large, the task of organizations can be modularized relatively easily; as we increase β, we increase the global coupling among projects, and thus decreasing the decomposability.

Using simulations we show the relationship between the nature of the environment, K and β, and the level of authority which is the most efficient for given structure of organization. For low values of complexity, decentralization is the most efficient. As we increase complexity, we see that increasing the degree of centralization increases firm performance. In this paper we have only focused on organizations of a few particular sizes and forms. An obvious extension is to consider a much wider set of organizational structures to see which ones perform the best under various environments. This extension will also require a more detailed treatment of the costs of the organization – a larger organization must incur more cost than a smaller one, for example. Here we looked at the implicit costs, which directly relates the speed of information processing, and its relation to the modularity of an environment in which an organization operates.

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