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REGULAR ARTICLE

Organizations undertaking complex projects in uncertain environments

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Abstract Recent evidence suggests that firms' environments are becoming more complex and uncertain. This paper investigates the relationship between the complexity of a firm's activities, environmental uncertainty and organizational structure. We assume agents are arranged hierarchically, but decisions can be made at different levels. We model a firm's activity set as a modified NK landscape. Via simulations, we find that centralized decision making generates a higher payoff in more complex and uncertain environments, and that a flatter structure is better for the organization with centralized decision making, provided the cost of information processing is low enough.

Keywords Environmental complexity · Information processing · Decision making · Organizational structure

JEL Classification C63 · L2

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1 Introduction

The internal structure of firms is changing in response to the increasing complexity and uncertainty of the environment. For example, Rajan and Wulf (2006), in their empirical study of 300 large U.S. corporations, demonstrate that firms have become flatter over time, in the sense that there are more positions directly reporting to the CEO, and the number of levels between division heads and the CEO has decreased. Chuma (2006), in his case study of the microlithography industry, argues that whether a firm is able to maintain its competitiveness depends on whether it can successfully restructure in the face of increasing environmental complexity.

What is the rationale behind organizations changing their internal structures in such a way? When do flatter organizations outperform more hierarchical ones? Does the answer depend on where the authority of decision making is located within the organization? In this paper, we try to answer these questions by constructing and simulating a model of information processing organizations that undertake complex projects in uncertain environments.

We model organizational projects (activities) as a modified NK landscape, which was investigated by Kauffman (1993) in his study of biological systems. In recent years, this approach has been increasingly used to model complex problems in general. A project consists of N components, each of which generates a value to the firm. The value of a component, however, can depend on its own configuration and the configuration of K other components; here a "configuration," $x_i \in \{0, 1\}$ is a decision about a particular project component. The value of the whole project (i.e., the value of a particular set of N configurations) is assumed to be the mean of the values that its components generate. Because of the interdependency among components, small changes in the project's configuration can have nonlinear effects on the value of the project as a whole. We modify the basic NK Landscape by combining it with the "β-model" proposed by Watts and Strogatz (1998). The β-model provides a convenient way of controlling for how the components of the projects are linked. In particular, the landscape can span between an ordered inter-linkage structure and a completely random structure.

The uncertainty of the environment is measured by the randomness of the project value. If there is no uncertainty, the project value of a given configuration remains constant, while in an uncertain environment, the same project configuration generates varying values from one period to another.

We assume that the organization is arranged hierarchically, but that decisions can be made at different levels. In our model of the organization, the level of decision making has a direct impact on the amount of information used in making a decision. A highly *decentralized* organization has decisions being made at the lowest level of the hierarchy and with agents having the least amount of information; a highly *centralized* organization has decisions being made at the top of the hierarchy, where the top agent has full information about the value of the project. For simplicity and ease of analysis, we explore only two types of hierarchical organizations, which have either two or three layers of agents. The two layer organization has agents at the bottom layer reporting directly to the top; the three layer organization has the agents at the bottom layer reporting to a middle layer of managers, who, in turn, report to the top manager. Thus, the two layer organization is *flatter* than the three layer organization.

Through extensive simulations of the model, we find that centralized decision making generates a higher value for more complex projects and in uncertain environments; and that a flatter structure is better for organizations with centralized decision making provided that the costs of information processing is relatively low. Our findings can explain the recent trend that Rajan and Wulf (2006) and Chuma (2006) illustrate: organizations are becoming flatter in response to the increasing complexity of the goods and services that they produce, and the increasing uncertainty of the environment in which they operate. Our findings indicate that such structural changes by organizations have become beneficial because of the recent advances in information and communication technology that have lowered information processing cost within organizations.

The rest of the paper is organized as follows. The related literature is reviewed in Sect. 2. Next, Sect. 3 presents the model. In Sect. 4, we discuss our simulation results; and Sect. 5 concludes.

2 Related literature

2.1 Information processing organizations

Our work fits within the crossroads of models of information processing organizations and the study of complex landscapes. The work of Rivkin and Siggelkow is closely aligned with ours. In a series of papers (Rivkin and Siggelkow 2003; Siggelkow and Rivkin 2005, 2006) they use variations of the same basic model to illustrate how the relationship between organizational design and the environment can affect firm performance. In their basic 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.

Their 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 searches the landscape and makes decisions about which locations (project configurations) 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 and focus of analysis differ 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 particular, our focus is to understand when a flat organization is better: under what environmental circumstances will a two layer organization have greater profits than a three layer organization? In addition, we explicitly consider the costs to the organization for processing information, which is crucial in comparing organizations of different structures and sizes.

Another model of an information processing organization comes from Radner (1992, 1993), who depicts a firm as a type of problem solving machine. Each agent performs an associative operation (e.g., adding numbers, or finding the maximum number), and passes 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 be easily decomposed and are fixed, the roles of search and project complexity in processing information are not explored. As in Radner's paper, however, we model the costs of information processing as the "delay," or speed it takes for an organization to reach a decision.

In addition, Barr and Saraceno (2002) model a 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 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 on the decentralization of information processing.

2.2 Complex landscapes

In recent years, researchers have begun to search for modeling tools that incorporate complex environments, whose components tend to interact in a nonlinear way. For example, the choice of production technology for a 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). Therefore, the production process in general is a complex set of interrelated activities, and a change in one activity can have implications for the performance of other parts of the firm.

In this vein, models have emerged to explore these complex systems via NK Landscapes. Developed for the study of biological systems (Kauffman 1993), these models have natural implications for complex social and economic systems, such as the internal working of a firm and the nature of technological innovation.

Papers by Levinthal and his coauthors explore organizational performance on rugged landscapes (Gavetti and Levinthal 2000; Levinthal and Warglien 1999; Levinthal 2000). For example, Gavetti and Levinthal (2000) 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.

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

Auerswald et al. (2000) model the mapping between technology choice and labor costs as a rugged landscape. They 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) model search in a technology landscape. They find that early in the search process it is optimal to search relatively far, but as a firm improves its production methods, search should become more localized.

3 The model

We consider organizations undertaking complex projects in uncertain environments. In this section, we first describe how we model projects with varying degrees of complexity. We then discuss environmental uncertainty. Finally, we describe our model of information processing organizations.

3.1 Complex projects

We employ an NK Landscape (Kauffman 1993) to represent a project space. We assume that a project that an organization undertakes consists of N components, each of which can be configured to either zero or one.[1] Each component generates a value, which depends on its own configuration and the configuration of $K \in \{0, \ldots, N-1\}$ other components. We assume that value of the project as a whole is the average of the values generated by its N components. We normalize the value of each component to lie between zero and one, so that the value of the project also lies between zero and one. Furthermore, initial configuration payoffs are generated from a uniform [0, 1] distribution.

When modeled in this way, the number of possible project configurations is 2^N, a potentially large space in which organizations have to search for relatively profitable projects. The parameter K captures the complexity of the project space. When $K = 0$, there is no interdependency among components, thus, changing the configuration of one component results in smooth changes of the value of the project. The larger the value of K, the more interdependencies there will be among components. When K is large, changing the configuration of one component affects the value of many other components, and thus will have a non-linear effect on the value of the project.

Kauffman (1993), in his original model, assumed that the value of a component is affected by K other components randomly chosen from $N - 1$ remaining components. We add some structures to the pattern of interdependencies by introducing the parameter $\beta \in [0, 1]$, that controls the degree to which the components are *locally* coupled. The structure of interdependencies is created as follows. We begin by assuming that, for a given K, the components that affect each x_i (x_i's "neighbors") are the K nearest ones. For example, when $K = 2$, the payoff associated with x_i is

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[1] The assumption that each component can be configured to be either zero or one is made for simplicity. One can easily extend the model so that a component can be configured in many ways. If the number of possible configuration of the component is c, then the number of possible configurations of projects becomes c^N.

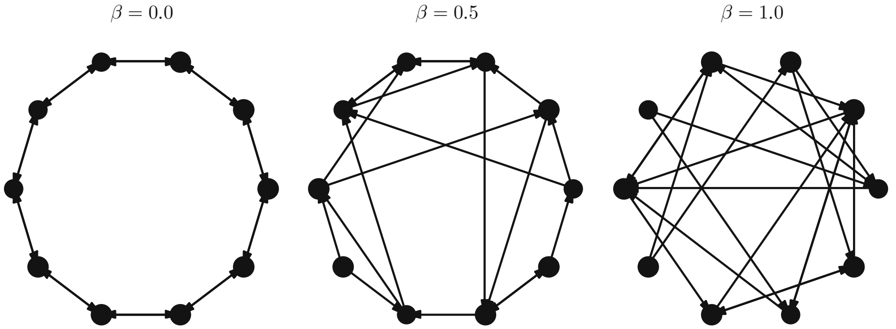

Fig. 1 Example of connectedness among bits of the landscapes for three values of β: $\beta = 0$ (*left*), $\beta = 0.5$ (*center*), and $\beta = 1.0$ (*right*). $N = 10$ and $K = 2$

determined by the configuration of components x_{i-1} and x_{i+1}. The linkage structure is considered circular in the sense that the value of the left-most elements are affected by the configuration of the right-most neighbors. For example, the nearest 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 component. Therefore, when $\beta = 0$, the value of x_i is affected by the configuration of its K nearest components. When $\beta = 0.5$, on average, half of the connections are replaced with randomly chosen ones. And when $\beta = 1$, all the connections are randomly rewired. This method of spanning the space between ordered and random structures of interdependency has been proposed by Watts and Strogatz (1998).[3] See Fig. 1 for an example.[4] Note that the landscape is rewired only once before firms begin searching.

While the parameter K governs the nonlinearity of the landscape, the parameter β governs the localness of interdependencies, although these two are not completely independent. For example, when $K = 0$ (the project landscape is fully unconnected), β is irrelevant. It is also the case that when $K = N - 1$ (the project space is fully coupled), β is irrelevant. The interesting cases are when K is relatively small compared to N. In these cases, the parameter β, which governs the localness of interdependencies, can also be interpreted as the degree to which the landscape can be modularized (Langlois 2002). 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 divides up the projects of size N into sub-projects of smaller sizes that consist of consecutive components, and assigns them to agents within the organization. Depending on β, a decision of one agent to change the configuration of a component may in turn affect the payoff of the sub-projects of other agents. The

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

[3] Note that after rewiring the landscape, it is possible that the payoff for x_i is affected by some x_j but not the other way around. This is because the underlying graph of interdependencies is directed.

[4] Watts and Strogatz (1998) found that in between the two extremes ($\beta = 0$ and $\beta = 1$), there exists "small world" structures—structures with high local clustering and a low path length—that can be observed in varieties of settings from social interactions such as the structure of friendships and co-authorship to more technological ones such as the internet and electricity grids.

larger is β the more random the distribution of interactions among components, thus a decision by one division manager may have an effect on many other divisions.[5]

3.2 Environmental uncertainty

To capture the uncertainty of the environment in which organizations operate, we introduce a parameter, $p \in [0, 1]$, such that with probability p the value of a component associated with each possible configuration of the project is replaced with a randomly chosen value between zero and one. If p is zero, then once the landscape is generated, the value associated with each possible configuration will be fixed over time. Thus, given the project's configuration, organizations always receive the same payoff. When $p > 0$, the value that the project generates varies, even without changing its configuration. The larger the p, the more fluid or uncertain is the environment in which organizations operate.

3.3 The organization

The general organizational structure is given as a directed graph, where information flows from the bottom agents to the top agent. We generate organizations based on three parameters, $b > 1$, $d \in \{1, 2\}$, and $a \in \{0, \ldots, d\}$. The value of b, the "branching ratio," is the number of subordinates per manager. The "depth," d, is the number of vertical layers. The level of authority, a, tells which layer has the decision making authority within the organization; and it captures the degree of centralization in decision making. When $a = 0$, the final decision is made at the top layer, thus the decision making is fully centralized. When $a = d$ decision making is fully decentralized, i.e., the final decisions are made at the bottom layer of the organization. The size of an organization, including the top agent, with branching ratio b and depth d is $\sum_{j=0}^{d} b^j$ where b^d agents are at the bottom of the hierarchy.

The organization divides up the projects into sub-projects and assigns them to the agents as follows. First each of the b agents in the second layer (from the top) are given "control" over the greatest integer number of components less than N/b (i.e., each managers is assigned $\lfloor N/b \rfloor$ components). If $b \lfloor N/b \rfloor \neq N$ then each agent in this layer is assigned additional components in turn, until the project is fully partitioned. If there is one more layer in the organization, the sub-project is further divided into smaller sub-sub-projects in a similar manner as described for agents in the second layer. Therefore, a project consisting of N components is fully partitioned among the agents in the bottom layer. Two examples of organizations are given in Fig. 2. We assume that each agent only observes the values generated by the components under his control, but does not have any direct knowledge about the larger interdependency structure (i.e., K or β). Note that agents can partially infer this interdependency from the components they oversee, but, because they do not observe the value of components

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[5] Given the way the landscape is constructed, $\beta = 0$ does not mean that environment is fully modularizable or decomposable, because there exists a chain of local interactions through K. Borrowing the terminology of Simon (1981), when $\beta = 0$ with small K, the environment is nearly decomposable.

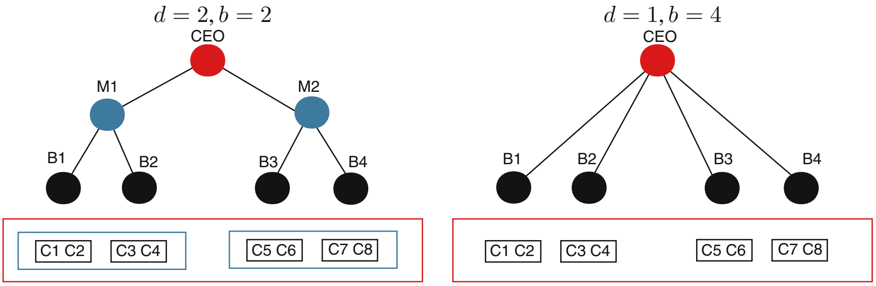


Fig. 2 Two examples of organizational structures and project division ($N = 8$). There are four agents in the bottom layer who are in charge of two components each. The CEO oversees the entire project. The left organization has three layers. The agents in the middle layer are in charge of sub-projects consisting of four components each

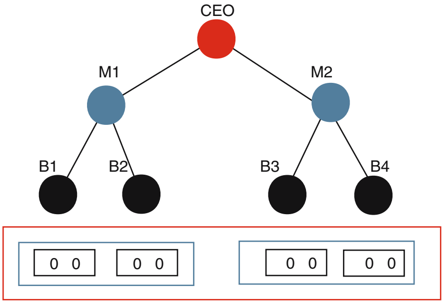
beyond their control, it is not possible for them to fully understand the underlying interdependency structure.

Organizational search starts from the agents in the bottom layer. Each agent there, when she searches, randomly changes the configuration of one of the components under her control. She proposes to make such a change if the value of the sub-project (or sub-sub-project) that she oversees becomes greater after the proposed change. The value of sub-project (or sub-sub-project) is assumed to be the average value of components that constitute it.

We assume that when evaluating the potential change, agents assume that no other change are made to the project configuration. This assumption is made on the grounds that each agent does not know what other agents are doing at the time of proposal evaluation. If the decision making authority rests with the bottom agents, i.e., $a = d$, then they implement the proposed changes to the project configuration. Once the changes are implemented, the organization receives the payoff (the value generated from the project.) If the decision making authority rests with layers above them, i.e., $a < d$, then these proposals are transmitted to the next layer above.

The agents in this level will evaluate the received proposal with a wider scope, as they oversee a larger part of the project. That is, the proposals received will be joined together from the subordinates, and evaluated using a "holding constant" approach, in the following sense. Let's say there are two subordinates each with a sub-sub-project under their control. Further, let's say each of the two subordinates passes up a new sub-sub-project. The manager then joins the new proposal of one agent with the old proposal of the other agent. Thus the manager evaluates a combined sub-proposal with only a single configuration change; but the manager evaluates two of these proposals, one from each subordinate.

The managers then propose the change (or no change) that generates the highest value for the division they control. If they have the decision making authority, they implement the proposed changes and the organization receives the payoff. If the decision making authority is in the layer above them, they pass up the proposal to the next layer. The agent who receives these proposals will act in a similar manner as just described. This process is summarized in Fig. 3.



Current project configuration: 00 00 00 00.

Bottom agents consider potential configuration changes and choose the one with a higher value for the sub-sub-project. Example:

	Status Quo	New Conf.		Chosen
B1	00	10	→	10
B2	00	01	→	01
B3	00	01	→	01
B4	00	10	→	10

Case 1: Authority at the bottom: a = d

The proposal will be implemented. **New project configuration: 10 01 01 10**

Case 2: Authority at the higher level: a < d

The proposal will be passed up. Each agent who receives the proposal picks the one that generates the highest value for for the sub-project among the received proposals and status quo. Example:

	Status Quo	Received Prop. 1	Received Prop.2		Chosen
M1	00 00	10 00 (from B1)	00 01 (from B2)	→	10 00
M2	00 00	01 00 (from B3)	00 10 (from B4)	→	00 10

Case 2-1: Authority at the middle: a = 1

The proposal will be implemented. **New project configuration: 10 00 00 10**

Case 2-2: Authority at the top: a = 0

The proposal will be passed up. Among the received proposals, including the status quo, CEO picks the one that generates the highest value and implements it. Example:

	Status Quo	Received Prop. 1	Received Prop.2		Chosen
CEO	00 00 00 00	10 00 00 00 (from M1)	00 00 00 10 (from M2)	→	10 00 00 00

New project configuration: **10 00 00 00**

Fig. 3 Examples of organizational search and information processing, $N = 8$, $b = 2$, $d = 2$. As the authority of decision making moves to the top of the hierarchy, fewer changes to the project are being made each period, but the decision is based on a greater scope

Note that it is possible to extend the model to have managers consider more proposals beyond those generated by the "holding constant" algorithm (which is a maximum of b different proposals). We leave this extension for further work for the following reasons. First, it introduces another level of complexity to the model, since there are several different types of algorithms that agents could use to select proposals. For example, they could choose among all possible combinations, some randomly chosen subset or some other rule. Second, we keep the algorithm simple because the focus is on the tradeoff between speed and the scope of decision making (i.e., how many bits agents see when making a decision), holding the proposal evaluation method constant. Changing the method of proposal evaluation can complicate this tradeoff.

We explicitly introduce, although in a very simple fashion, a cost of organizational search and information processing in order to highlight the pros and cons of the various organizational structures we consider. Our focus is on the algorithmic "delay" involved with selecting the project configuration. The main costs of doing so are the time costs involved with generating a decision (Radner 1992). In short, the faster that information can be processed, all else equal, the lower the costs.

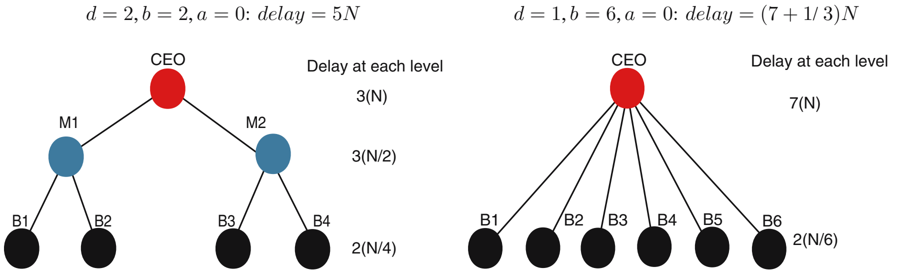


Fig. 4 Maximum delay for information processing in two organizations, $d = 2, b = 2, a = 0$ (*left*) and $d = 1, b = 6, a = 0$ (*right*). Note that both organizations have the same number of agents, but arranged differently

Information processing costs depend on two activities of the agents in the organization. The first is based on the (maximum) number of proposals agents evaluate at each level; we call this the *decision costs*, since it is a measure of the length of time it takes an agent to choose among the several proposals under consideration. Thus, all else equal, an increase in the value of b will increase the number of proposals that agents evaluate each period; however, each agent will evaluate smaller sized proposals. Second, evaluating each proposal takes time since each agent must determine the payoff of each proposal under consideration, these *evaluation costs* are increasing with the degree of centralization, since the higher the level at which decisions are being made, the larger the proposals the agents have to consider.

Each period, agents at the bottom layer of the organization evaluate a new proposal consisting of N/b^d components by comparing it with the status quo, and then they pass up their chosen proposal, as described above. If agents in the middle layer then have to make a decision, they must first evaluate up to (but possibly less than) $b + 1$ proposals of length N/b, including re-evaluation of the status quo, and then they make a decision over the proposals. If the agent at the top has final authority, then she must evaluate up to $b + 1$ proposals[6] of length N, making both evaluations and decisions.

This gives a per period delay as

$$delay_t = 2\left(\frac{N}{b^d}\right) + \sum_{j=a}^{j=d-1} \max_i \left(\widehat{b^j_{i,t}} + 1\right)\left(\frac{N}{b^j}\right),$$

where b, d, a are the branching ratio, depth, and authority level, respectively; $\widehat{b^j_{i,t}}$ is the number of proposals the i^{th} agent in the j^{th} layer has received from his subordinates. The information processing cost is therefore $c_t = f(delay_t)$, where $f(\cdot)$ is a non-decreasing function. Two examples of delay are shown in Fig. 4.

An important feature of the cost function that should be noted here is that a centralized network with only two layers will have a greater delay than a centralized network with three layers. The reason is that the top agent will have to evaluate many new

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[6] Which again include the b new proposals received and one status quo.

proposals each period and this can result in a type of agent overload. A centralized 3-layer organization will have its middle managers "filtering" or screening out proposals from below; while this can lower the performance from search, it can have the benefit of lowering the delay. As we discuss below in Sect. 4, centralized organizations have the best performance when projects are complex and environment is uncertain, yet the benefit of centralization must be evaluated in light of higher information processing cost associated with this centralization.[7]

4 The results

The model has a total of seven parameters: four of them, $\{N, K, \beta, p\}$, determine the project space and the environment; the other three, $\{b, d, a\}$, determine a firm's internal structure (N, however, is fixed at $N = 100$, throughout the rest of the paper). Through a series of simulations, we investigate the relationship between organizational structure and performance in a variety of situations. Each simulation consists of 500 periods. We take the average per period project value from each realization. The computational experiment is repeated 500 times with varying random seeds for each set of parameter values. The results reported below, unless otherwise noted, are based on the mean of these 500 realizations.[8]

4.1 Level of decision making

Figure 5 shows the performance of organizations, without considering the information processing cost, with depth equal to two ($d = 2$) , branching ratio equal to two ($b = 2$), and with varying authority levels in four different combinations of project complexity and environmental uncertainty. The top (bottom) row shows a simple (complex) project, $K = 2$ ($K = 6$), while left (right) column corresponds to a certain (uncertain) environment, $p = 0$ ($p = 0.01$). In each panel, the performance of the organization with three different authority levels are shown versus the varying degrees of project modularity. The black line corresponds to the performance with fully centralized decision making, $a = 0$; the dashed gray line represents performance based on fully decentralized decision making, $a = d$; and the solid gray line is when authority rests with the middle layer, $a = 1$. The same set of results for a larger organization, one with depth equal to two ($d = 2$) and branching ratio equal to five ($b = 5$), is shown in Fig. 6.

In all of the four project–environment combinations, one can see that as the project becomes less modular, i.e., the greater is β, the organizations with more centralized decision making perform better. This is the case for both $b = 3, d = 2$ organizations (Fig. 5) and $b = 5, d = 2$ organizations (Fig. 6). This is quite intuitive because, as the project become less modular, a change in the configuration of one component can

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[7] In a similar manner, the possible benefits from managers evaluating other possible combinations of received proposals, rather just from those produced by the "holding constant" approach assumed in this paper, have to be evaluated in light of the increased costs associated with more evaluated proposals.

[8] The simulations were run in C++. The source code is available from the authors upon request.

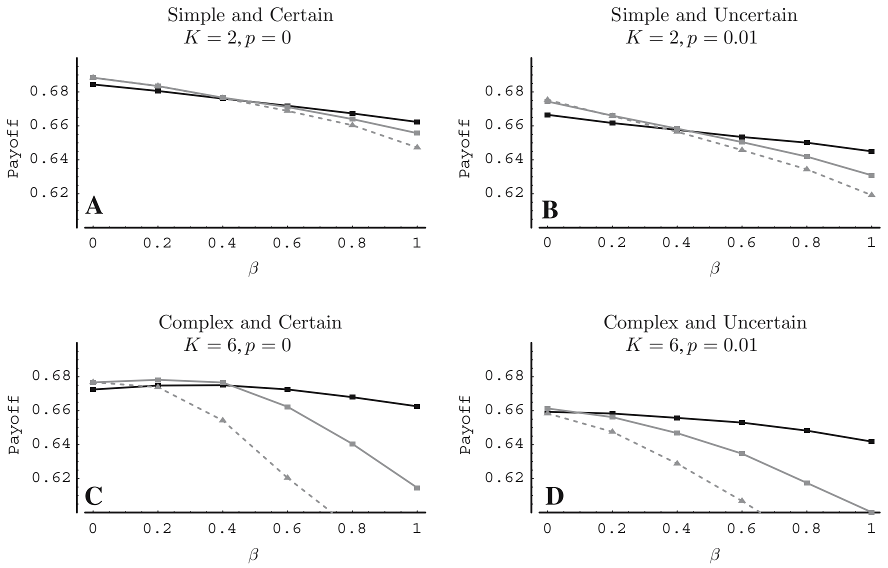

Fig. 5 Average product values (payoffs) for various β in four project–environment pairs: simple projects in a certain environment (**a**), simple projects in an uncertain environment (**b**), complex projects in a certain environment (**c**), and complex projects in an uncertain environment (**d**). Organizational structures considered are: $d = 2, b = 3$: *Black* $a = 0$, *solid gray* $a = 1$, *dashed gray* $a = 2$. Here we ignore the information processing cost

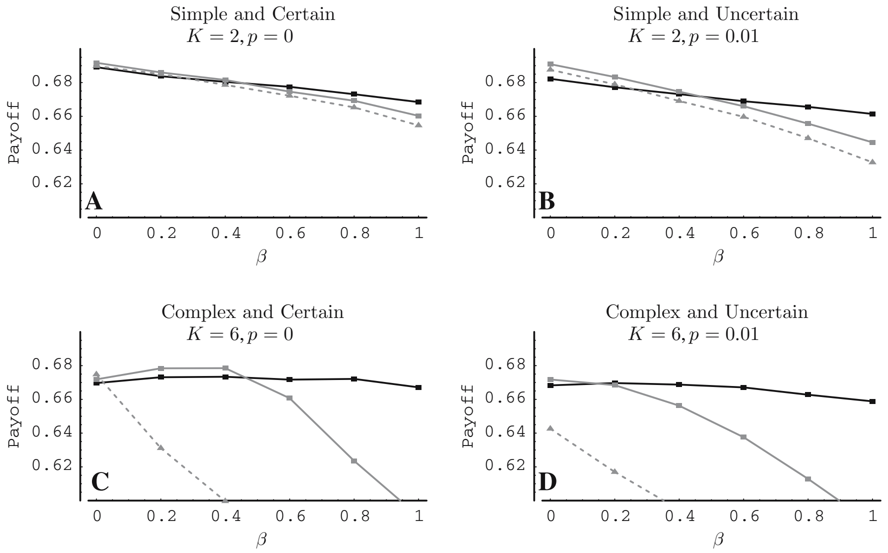

Fig. 6 Average product values (payoff) for various β in four project–environment pairs: simple projects in a certain environment (**a**), simple projects in an uncertain environment (**b**), complex projects in a certain environment (**c**), and complex project in an uncertain environment (**d**). Organizational structures considered are: $d = 2, b = 5$: *Black* $a = 0$, *solid gray* $a = 1$, *dashed gray* $a = 2$. Here we ignore the information processing cost

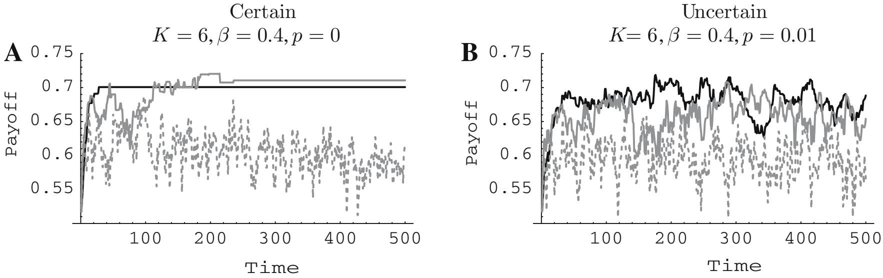

Fig. 7 Project value over time (from a single realization). $d = 2, b = 5$: *Black* $a = 0$, *solid gray* $a = 1$, *dashed gray* $a = 2$

have an impact on the value of the other components controlled by other division managers. Since decentralized decision making does not take an organizational-wide view into consideration, it will provide a relatively bad performance; thus the centralized decision making is relatively more profitable. On the other hand, if $\beta = 0$, so that the project is nearly decomposable, then decentralized decision making becomes better. This is because such an organization can make more changes to the project configuration, and these changes do not have effects on the other divisions of the firm.

An interesting observation is that while the performance of the completely decentralized firm ($a = 2$) relative to that of completely centralized decision making one ($a = 0$) monotonically declines as we increase β; the same is not true for the relative performance of the $a = 1$ organization. This can be best seen with a complex project in a certain environment (panel C) of Fig. 6. There, when $\beta \leq 0.4$ the relative performance of the $a = 1$ organization can increase. This finding replicates the work of Rivkin and Siggelkow (2003), and demonstrates what they call an organizational "sticking point." The sticking point concept can be best understood by a time series of the project values.

Figure 7 shows a realization of project values over 500 periods from a single simulation run for a particular sets of parameter values ($K = 6$, $\beta = 0.4$, $d = 2$, $b = 5$) under two conditions, a certain environment (left) and uncertain environment (right). As before, the black line corresponds to fully centralized decision making ($a = 0$), the dashed gray line represents the fully decentralized decision making ($a = 2$), and solid gray line shows the result of the intermediate case ($a = 1$). All three organizations at the very beginning of the simulation show increases in the project value. While the $a = 0$ organization never experiences a drop in performance, the other organizations do. In particular, the $a = 2$ organization demonstrates very volatile outcomes throughout the 500 periods.

The most interesting outcome is when $a = 1$; here we see that although the organization experiences some ups and downs in the project values, it eventually finds a project configuration that generates a higher value than the $a = 0$ organization does. Rivkin and Siggelkow (2003) attribute the failure of the $a = 0$ organization in locating the project that the $a = 1$ organization eventually finds because it gets "stuck" at an organizational sticking point. Recall how organizations search for new project configurations in our model. If the decisions are made at the top, then there will be at most only one configuration change implemented in each period, and such a change must increase the project's value. Therefore, such organizations will never experience a drop in the value of the project, but once they reach what is perceived to be a "local" peak–a place from which any single change in the configuration will lead to a drop in the performance, they stick to it and stop exploring for something better, regardless of whether it is the true global peak or not.

The problem of sticking points does not exist when the decisions are made at a lower level. In such organizations, there can be more than one change to a project's configuration implemented in each period. And, more importantly, the decision to implement such a change is based on whether it increases the value of a sub-project, not the value of the entire project. Thus a division head may implement a new configuration which lowers the performance of the organization as a whole. But such a change can push organizations to explore "further" for a better project than is the case with a centralized organization.[9]

In an uncertain environment (right panel of Fig. 7), regardless of the level of decision making, all the organizations experience volatility in their performance. What is interesting is that because of such volatility, all the organizations are constantly searching for a better project configuration. Organizations cannot stick to one practice when the environment surrounding them is constantly changing. Because of this, one may expect that an uncertain environment will favor the centralized decision making, especially, when the project is complex.

This is indeed what we see in Figs. 5 and 6. If we compare the region of β in which the completely centralized organization outperforms the others, it is greater in the uncertain environments when the project is complex ($K = 6$). But when the project is simple ($K = 2$), that is not the case. In fact, the performance of the decentralized organizations relative to that of the centralized ones become greater in uncertain environments when β is not too large. The reason for this is that when the environment is changing, the faster organization, in the sense that it explores many changes in a given period, is better. The benefits of the speed of decentralized organization become visible only when the project is simple and relatively modularizable, because in such cases, the sub-division or division head can implement changes without causing a drop in the performance of the organization as a whole.

4.2 Flatter versus steeper organizations

In the previous subsection, we saw that centralized decision making is preferred for organizations undertaking complex projects in uncertain environments. In this subsection, we consider the conditions when a flatter organization is better and in what sense, restricting our attention to organizations with centralized decision making. We focus only on the most "difficult" scenarios for the firm because of the importance of

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[9] The problem of organizational sticking points will be mitigated if managers evaluate other possible combinations of received proposals and implement more than one-bit changes. This is because doing so allows the organization to jump away from a perceived local peak.

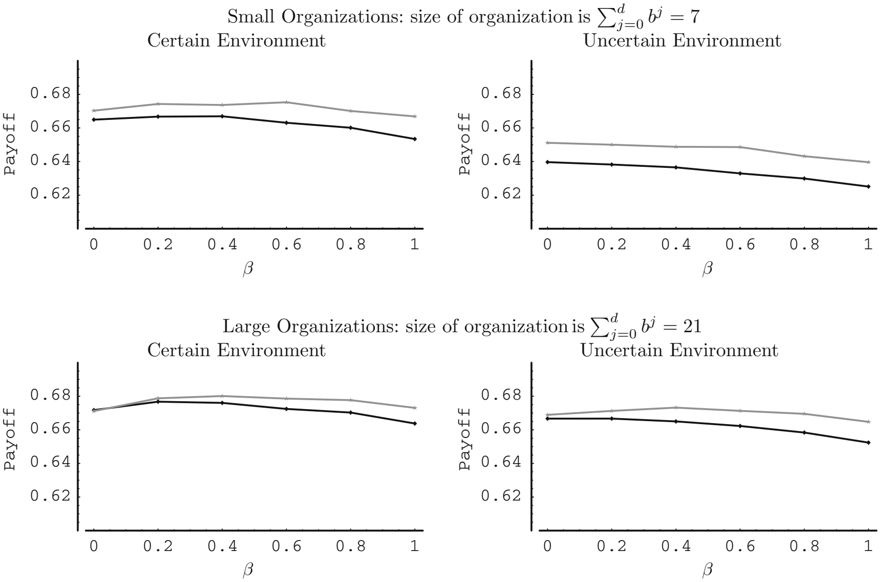

Fig. 8 Average project values for organizations of size 7 (*top*) and size 21 (*bottom*) for various β undertaking complex projects ($K = 6$) under certain ($p = 0$, *left*) and uncertain ($p = 0.01$, *right*) environments. *Black* $d = 2$, *gray* $d = 1$. For all the organizations, $a = 0$

understanding how firm organization and performance are affected in the new economy, marked by rapid technological and environmental change and complexity.

Figure 8 shows the performance of centralized organizations of the same size but with two different depths. The black lines show the performance of organizations with three layers ($d = 2$), while the gray lines correspond to those with flat structures (two layers, $d = 1$). We consider two different firm sizes, one small, with a total of 7 agents in the organization, and another larger organization with 21 agents.[10]

In all of the four panels in the Fig. 8, we observe that flatter organizations ($d = 1$) generate higher project values. The reason for this is because of the "filtering" of proposals by the middle layer in a $d = 2$ organization. Recall that in our model of organizational search and information processing, proposals are being sent up the hierarchy and evaluated at each level before they are finally implemented. In addition, the criteria of proposal selection differs from one layer to another within the organization. Thus, having an additional layer in the organization prevents potentially valuable proposals (for the organization as a whole) from reaching the agent at the top who has the decision making authority. The negative effect of filtering can be eliminated by having fewer layers between the top decision making agent and the bottom layer who send up new proposals.

We have demonstrated the benefit of centralized decision making for organizations undertaking complex projects in uncertain environments. We have also demonstrated

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[10] For the organization with size 7, if it is a two (three) layer organization, i.e., $d = 1$ ($d = 2$), then $b = 6$ ($b = 2$). When the size of the organization is 21 then for $d = 2$, $b = 4$, and for $d = 1$, $b = 20$.

that when decision making is centralized, having a flat structure can improve the performance of the organization. But a flat organization with centralized decision making is associated with higher information processing costs, as discussed in the previous section, and shown with the example given in Fig. 4. For the benefit of a flat organization with centralized decision making to outweigh the larger cost of information processing associated with this structure, the latter must be relatively low. The recent rapid advances in information technology and communication systems may have contributed to decrease the information processing cost within organizations; the parallel increases in project complexity and environmental uncertainty have generated the incentive for organizations to become flatter and more centralized.

5 Conclusion

In this paper we have presented a relatively simple model of information processing organizations undertaking complex projects in uncertain environments. The organization is modeled as a hierarchical network. The complex project space is modeled as a modified NK Landscape. We study the relationship between organizational structure, centralization/decentralization of decision making and firm performance, given various degrees of project complexity and environmental uncertainty.

Through extensive simulations of the model, we find that centralized decision making generates a higher value for more complex projects and in uncertain environments; flatter structures are better for organizations with centralized decision making provided that the cost of information processing is low enough. Our finding explains the facts reported, for example, by Rajan and Wulf (2006) and Chuma (2006), that organizations are now flatter and more centralized in response to increasing technological complexity and environmental uncertainty.

Our model, however, does not explain the process of organizational restructuring due to this increased complexity and uncertainty. The endogenous response of organizations to changing environments is left for future work. In considering this relationship, one needs to consider (1) the role of agent incentives (Bethel and Liebeskind 1993), (2) the effect of firm history-dependent factors and “structural inertia” (Ruef 1997), (3) the degree to which a firm’s industry is highly competitive or not (Disney et al. 2003), and (4) the direction and nature of technological change (Tushman and Anderson 1986).

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