Complexity, Uncertainty, Organizational Congruency

Nobuyuki Hanaki* Hideo Owan †

August 13, 2008

Very Preliminary and Incomplete!

We consider organizations undertaking complex projects in uncertain environments employing an NK Landscape framework (Kaufman, 1993). Our main focus is to investigate the effect of "congruency" in choosing the direction of search. Product development practitioners often argue that it is desirable to share a product concept and restrict the directions of exploratory efforts to coordinate the activities of members involved in the product development process. Unless complementarity or integrity is important enough, however, restricting the range of exploration could lead to a suboptimal outcome. In this paper, we first assume that the organization conducts decentralized search over possible project configurations but provide its members with "congruency incentive," namely lower payoff to configuration changes that are not congruous to a certain direction. We find that congruency can improve the performance of organizations: the mean payoff is maximized at a certain level of congruency when projects are complex enough. However, this benefit disappears as the environment becomes more uncertain.

1 Model

We consider organizations undertaking complex projects in uncertain environments. Our main focus is to investigate the effect of "congruency" in the performance of organizations

*University of Tsukuba, hanaki@dpipe.tsukuba.ac.jp
†Aoyama Gakuin University and Hitotsubashi University, owan@gsim.aoyama.ac.jp

under various levels of complexity and environmental uncertainty. In this section, we first describe how we represent the complexity of a project and environmental uncertainty. We then provide an description "congruency incentive" given to members of organizations.

We employ an NK Landscape (Kauffman, 1993) to represent a project space. We assume that a project 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 $K \in \{0, ..., N-1\}$ other randomly components[2] as follows.

Let $x_i \in \{0,1\}$ be the configuration of component i, Γ_i be the set of K components that influence the value of component i, and $\mathbf{X}_i \in \{0,1\}^K$ be the vector of configurations of those K components in Γ_i. Now, let $\pi(x_i, \mathbf{X}_i)$ represent the value component i generates when it is configured as x_i and K other components that influence i are configured as $\mathbf{X}_i$. $\pi(x_i, \mathbf{X}_i)$ is defined by assigning values drawn randomly from $U[0,1]$ to each possible x_i and $\mathbf{X}_i$.

The value of the project as a whole, $\Pi(\mathbf{X})$ where $\mathbf{X} \in \{0,1\}^N = \{x_1, x_2, ..., x_{N-1}, x_N\}$, is assumed to be the average value generated by its N components, thus $\Pi(\mathbf{X}) = \frac{\sum_i \pi(x_i, \mathbf{X}_i)}{N}$.

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.

[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.

[2]One can also consider many other possible structures of interdependencies among components. Rivkin and Siggelkow (2007) demonstrates that the structure of interdependencies, even controlling for K, affect the complexity of the projects and effectiveness of search strategies employed by organization.

1.1 Uncertainty

To capture the uncertainty of the environment in which organizations operate, we introduce a parameter $p \in [0,1]$ such that in each period and for each possible project configuration $\mathbf{X}$, $\pi(x_i, \mathbf{X}_i))$ is redefined randomly to a value drawn from $U[0,1]$ with probability p. Thus when p is zero, the value associated with each possible configuration of the project will be constant over time, while with a higher value of p, the value of the project changes even without modifying its configurations.

1.2 Organizational congruency and search

We assume that organizations conduct decentralized search over the possible project configurations. It is decentralized search because an organization will divide up a project into several smaller sub-projects and delegates those sub-projects to its members, then each member of the organization independently searches for better sub-project configuration in the manner described below.

The organization consisting of M members divides up the project into M sub-projects each consisting of distinct N/M consecutive components and assign them to its members. Let S^m be the set of components assigned to member i of the organization. Call S^m the sub-project assigned to member m.[3]

Each period, each member of the organization will randomly chose one of the components assigned to them, and consider changing its configuration. She decides to change the configuration if doing so will increase the *net value of the sub-project* she is in charge of, taking the project configuration at the beginning of the period as given. It is important to note here that we are assuming that each member only care about the net value of the sub-project and not the value of the project as a whole. The *net value of the sub-project* for member m, NV^m, is defined as the value of sub-project net of congruency incentive given

[3]When it is not possible to divide up the project into S sub-projects of equal size, it will be divide in such a way that the difference in the size of sub-projects are minimized across members.

to her by the organization as follows:

$$NV^m = \frac{1}{|S^m|} \sum_{i \in S^m} (\pi(x_i, \mathbf{X}_i) - \gamma g(x_i, \mathbf{X}_i))$$

where

$$g(x_i, \mathbf{X}_i) = \frac{\sum_{j \in \Gamma_i} |x_i - x_j|}{K}$$

which measures the average mis-configurations between component i and $j \in \Gamma_i$. It is zero when i and all $j \in \Gamma_i$ are configured in the same, while it will be one when all the components $j \in \Gamma_i$ are configured differently from the component i.

As can be seen, the higher the γ is, the higher it is the incentive given to each member of the organization to reduce the mis-configuration among $K + 1$ components. We call this congruency incentive because by placing this factor, the organization can coordinate the direction of search by its members who, by assumption, make uncoordinated decisions. This is clear if one recalls that because of the random interdependency structure among $K + 1$ components of the projects and the way sub-projects are constructed and assigned to members of the organization, the value of component i in the sub-project assigned to a member is likely to depend on the configuration of components that are assigned to many other members of the organization.

It should be noted that it is not obvious at all that an organization giving a high "congruency incentive" to its members enhances the performance of organization. Because doing so the organization is restricting the space of possible configuration searched by its members. How do the complexity of the project and uncertainty of the environment affect benefit (and cost) of "congruency"? We provide answers to this question in the next section.

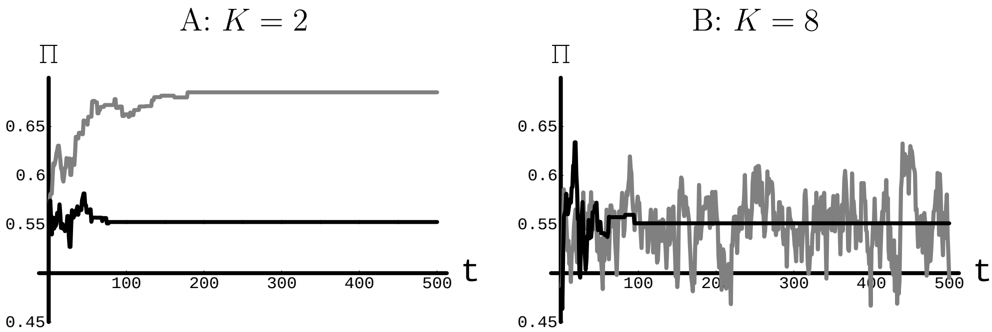

Figure 1: Time series of project value, Π, for two levels of complexity $K = 2$ (left) and $K = 8$ (right). In each figure, outcomes from two levels of congruency are reported $\gamma = 0.0$ (in gray) and $\gamma = 1.0$ (in black). $M = 10$, $p = 0.0$

2 Preliminary Results

In the simulation of the model, we have fixed the size of project, N, to be 100, the size of organization, M, to be either 10 or 20 while varying degree of interdependency K, degree of environmental uncertainty, p, strength of congruency incentives γ. In one simulation, we assume organization continue to search for 500 periods.

Figure 1 shows a few time series of project value Π from two levels of complexity, $K = 2$ (left) and $K = 8$ (right), and two levels of congruency incentives, $\gamma = 0.0$ (gray) and $\gamma = 1.0$ (black), without any uncertainty $p = 0$.

One can immediately see from Fig. 1 that when the level of complexity is very low, it may not be a good idea for an organization to give strong congruency incentive to its members. The negative effect of restricting the search space is so strong that project value in not increased at all. One the other hand, when the level of complexity is higher, the result is less clear. When there is no congruency incentive given, the project value fluctuates drastically over time,[4] while it is not the case with the strong congruency incentive. It is not clear from the figure, on average which level of congruency generates higher project values.

Outcomes shown in Fig. 1 suggest that we should not measure the performance of an

[4]This finding is not new. Earlier studies on organizational design in complex environment, (see, for example, Rivkin and Siggelkow, 2003, among others), have also reported that the same.

organization just by average project values over the search process. Instead, there may be cases where we want to measure the performance in terms of both average project values as well as the variance of it. Thus in the rest of the section, we present both the mean, μ_{Π}, and standard deviation, σ_{Π}, of per period project values from last 250 periods of simulation.

2.1 Complexity and congruency

We first consider the case where there is no uncertainty, $p = 0$, and see the effect of various level of congruency in performance of organizations.

Figure 2 shows the result for three level of complexity $K = 4$ (left), $K = 8$ (center), and $K = 12$ (right). The top row shows the mean per period payoff, and the standard deviation is shown in the bottom (both averaged over 100 simulation runs). One can see from the bottom rows of the figure that the standard deviation of per period payoff within a simulation run becomes lower as the congruency incentive, γ, becomes higher regardless of the level of complexity. This confirms the pattern we saw in the time series plots in Fig. 1.

There, however, is no such monotonic relationship between congruency incentive and the mean per period payoff. When level of complexity is low, $K = 4$, the higher congruency lowers the mean payoff. For higher levels of complexity, there is a range of congruency incentives, $0.0 \leq \gamma \leq 0.6$, in which mean payoff is not affect by it. Then for $0.6 < \gamma \leq 0.8$, the payoff increases with γ before it starts falling with it for higher values of γ. The increase in the mean payoff is smaller for $K = 8$ than $K = 12$. This result suggests that when the complexity level of the project is high, congruency, although it has to be at the right level, can increase the performance of organization, both in terms of higher mean payoffs and lower volatility.

The higher mean per period payoff, however, is not always guaranteed even when right level of congruency is given. As demonstrated by wider one standard deviation error ranges in the mean payoff figure, the per period payoff can vary quite drastically from one simulation run to the other when congruency is high. It makes sense, though, because a high congruency

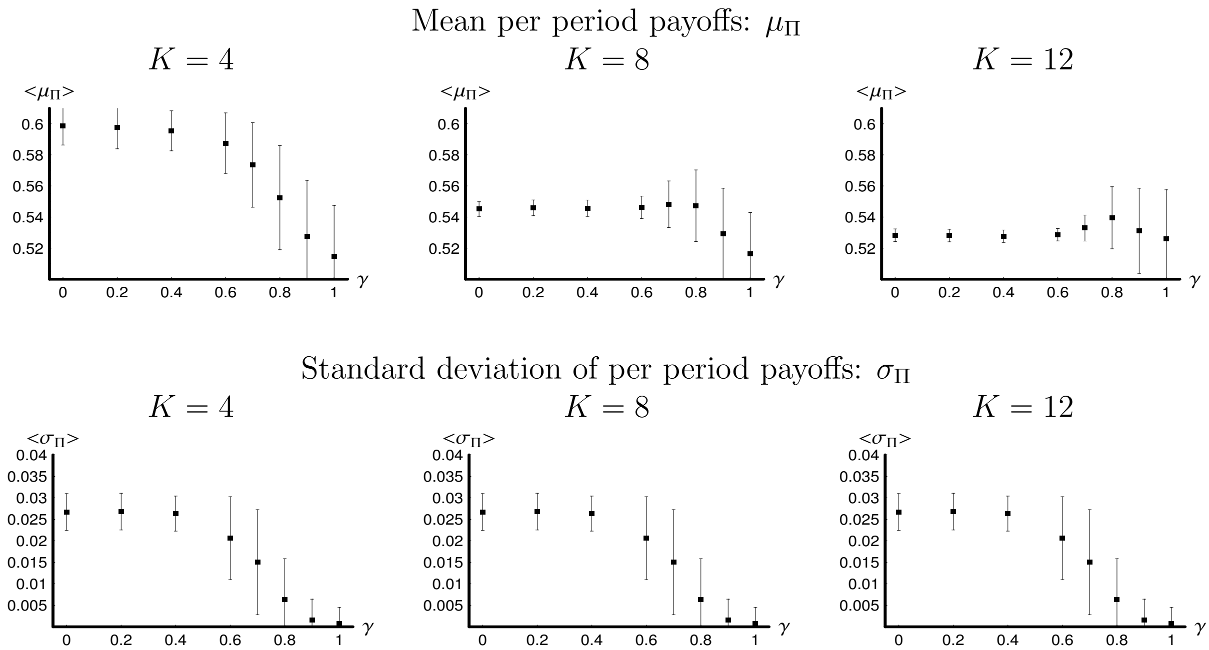

Figure 2: Mean (top) and standard deviation (bottom) of per period payoff from last 250 periods of simulation runs for various congruency incentive, γ, in three levels of complexity, $K = 4$ (left), $K = 8$ (center), $K = 12$ (right). Averaged over 100 simulation runs. One standard deviation error bars are also shown. $M = 10$, $p = 0.0$

limits the range and direction of search process, but if a wrong direction is given, the resulting payoff will be low. In our simulation, the search directions are determined randomly.[5]

The positive effects of congruency on the mean payoffs when complexity is high becomes more pronounced for larger organization. Figure 3 shows the same information as in Fig. 2 for organization with 20 members ($M = 20$). The value of γ that generates the highest mean per period payoffs differ, in case of $K = 8$, from the $M = 10$ case shown above.

2.2 Uncertainty and Congruency

We have seen that congruency, when set at the right level, can enhance the performance of organization, in terms of a higher mean per period payoff and a lower variance of per period payoff, undertaking highly complex project. How does a presence of uncertainty influence

[5]Precisely, the direction of the search is determined by the initial configuration of the projects as well as early stage of the search process.

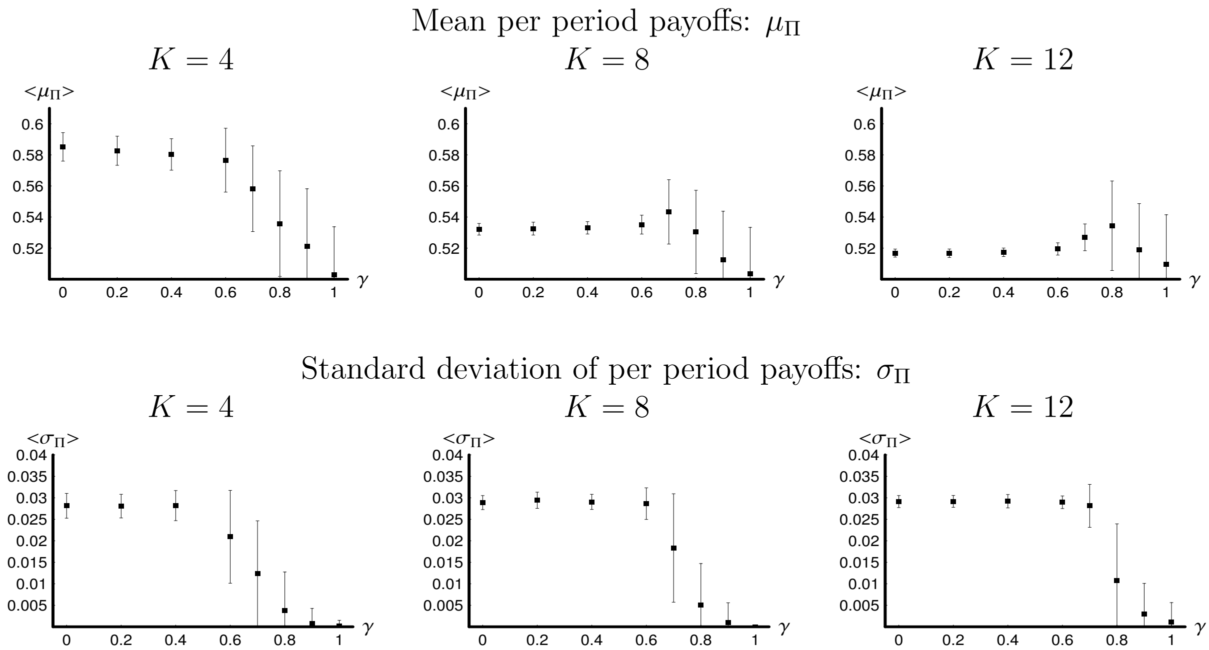

Figure 3: Mean (top) and standard deviation (bottom) of per period payoff from last 250 periods of simulation runs for various congruency incentive, γ, in three levels of complexity, $K = 4$ (left), $K = 8$ (center), $K = 12$ (right). Averaged over 100 simulation runs. One standard deviation error bars are also shown. $M = 20$, $p = 0.0$

the effect of congruency on performance?

Figure 4 shows the mean and the standard deviation of per period payoffs against γ for three levels of complexity. The uncertainty parameter is set that $p = 0.05$. First point to note is that congruency,γ, has no impact in reducing the variance of per period payoff. The environmental uncertainty is so high that regardless of congruency, all the organization faces volatile payoffs. The second point is that the positive effect on mean payoff, although it still exists for $K = 12$, is much smaller than the case without uncertainty. The same observation can be made for a larger organization with $M = 20$ shown in Fig 5.

Thus, one can conclude, in the presence of high environmental uncertainties, providing congruency incentive is not very useful both in terms of reducing the payoff fluctuation and increasing the mean payoff in complex situation.

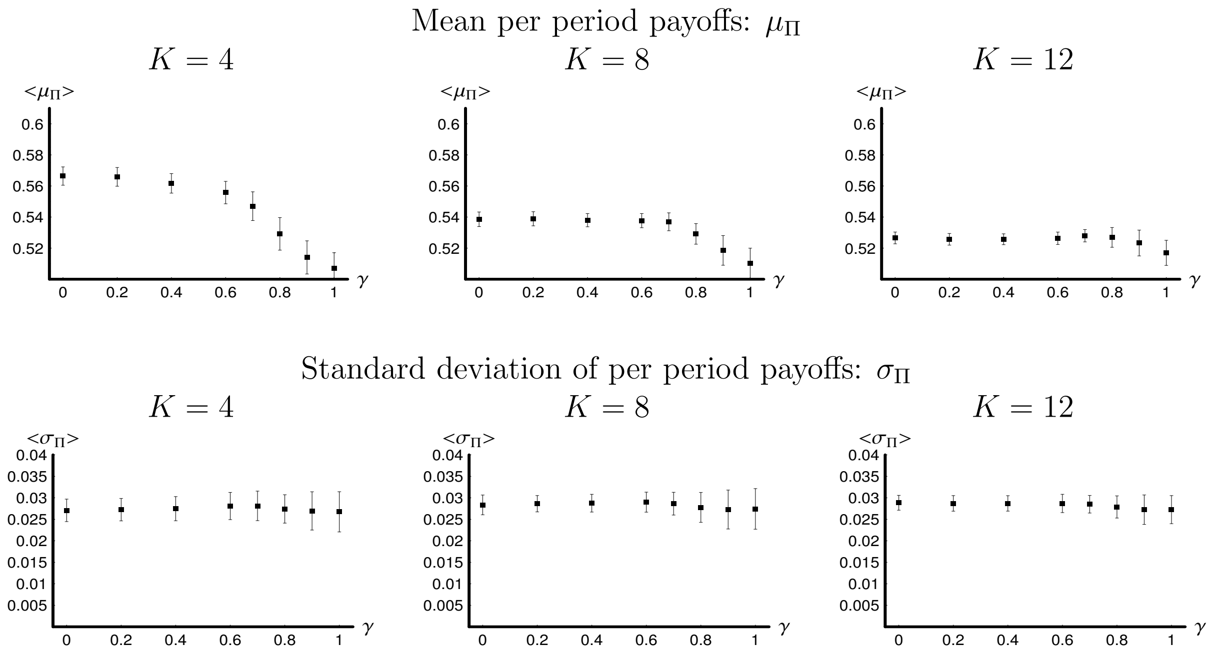

Figure 4: Mean (top) and standard deviation (bottom) of per period payoff from last 250 periods of simulation runs for various congruency incentive, γ, in three levels of complexity, $K = 4$ (left), $K = 8$ (center), $K = 12$ (right). Averaged over 100 simulation runs. One standard deviation error bars are also shown. $M = 10$, $p = 0.05$

References

Kauffman, S. (1993): *The Origins of Order: Self-Organization and Selection in Evolution.* Oxford University Press.

Rivkin, J. W., and N. Siggelkow (2003): "Balancing Search and Stability: Interdependencies Among Elements Of Organizational Design," *Management Science*, 49, 290–311.

——— (2007): "Patterned Interaction in Complex Systems: Implications for Exploration," *Management Science*, 53, 1068–1085.

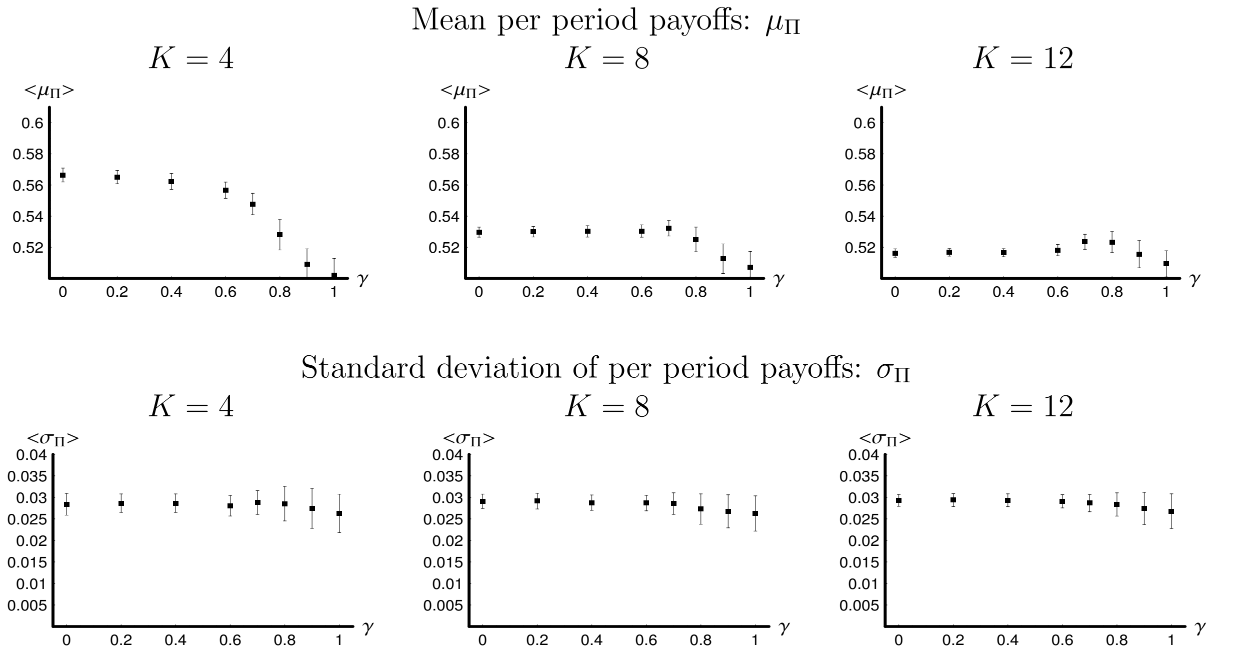

Figure 5: Mean (top) and standard deviation (bottom) of per period payoff from last 250 periods of simulation runs for various congruency incentive, γ, in three levels of complexity, $K = 4$ (left), $K = 8$ (center), $K = 12$ (right). Averaged over 100 simulation runs. One standard deviation error bars are also shown. $M = 20$, $p = 0.05$