Complexity, Robustness, and Performance: Trade–Offs in Organizational Design

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Abstract

This paper analyses the trade-offs between structural complexity (the degree of detail of information necessary to correctly assign agents to positions), robustness (the degree to which an organization can insulate itself from changes in the environment), and performance (expected value of implemented projects). Within the context of simple project selection structures, it is shown that organizations of least complexity perform well in extreme environments, that more complex organizations are quite robust, but that the most robust structure is one of least complexity.

JEL codes: L21, L23

Keywords: organization, complexity, robustness, project selection

1 Introduction

If an organizational designer has to choose between two organizational structures, one prediction could be that she will choose the one generating the higher expected profit. Casual evidence suggests that other considerations also play a role in the designer's decision. First, it is common to refer to the business environment as 'volatile' ('the only constant is change'). As re-organizations are costly, designers are likely to prefer a 'robust' organization to a 'sensitive' one. One obvious trade-off then that could exist is between the performance of an organization in a given environment and the sensitivity of performance to changes in the environment. A second consideration when choosing an organization is the amount of information needed to realize the higher performance organization. The job of designing and implementing the optimal organization may be too difficult and too time consuming to be considered seriously ('that would take a rocket scientist' and 'we have to move quickly'). This points to a possible trade-off between performance and complexity.

In this paper I analyse the relationship between complexity, robustness and performance. I answer the following questions: What does it mean for an organization to be complex? How can one measure degrees of complexity? How could one measure robustness? Are more complex organizations more profitable but less robust than less complex ones, or rather more robust, but less profitable?

As I want to focus on the development of these concepts and the way they are related, I use a very simple model of individual behaviour and focus on a single aspect of what organization's do. Following Sah and Stiglitz (1985,1986), I describe an organization as a sequential decision structure that selects projects. Projects can be either good or bad. A good project, when implemented by the organization, yields a positive payoff whereas an implemented, bad project gives rise to a loss. A percentage of the initial pool of projects is good. Screening takes place by error–prone agents: some good projects are rejected, while some bad projects are accepted. As in Sah and Stiglitz, the probabilities of acceptance are exogenously given. Whether employees have been screening the project before him, and will screen it depending on his decision after him, is immaterial to the employee presently considering whether according to him the project should be accepted or rejected.[1] As said, the assumption is made to simplify analysis and to emphasize concepts. These concepts could have been introduced in a model in which an employee rationally processes any information he may have himself and may deduce from the fact that a project lands on his desk. However, the analysis would have been much more complicated.

To be able to discuss complexity, I extend the Sah and Stiglitz setting by introducing heterogeneous agents (some agents accept less bad projects and more good projects than others) and by studying two more screening structures, see Figure 1. Sah and Stiglitz studied (the two-person version of) the 'hierarchy' and the 'polyarchy'.[2] The nodes stand for organizational departments, bureaus or desks and the directed edges

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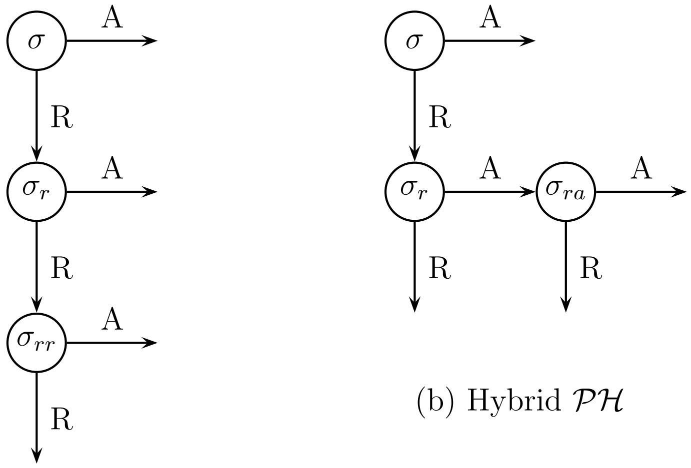
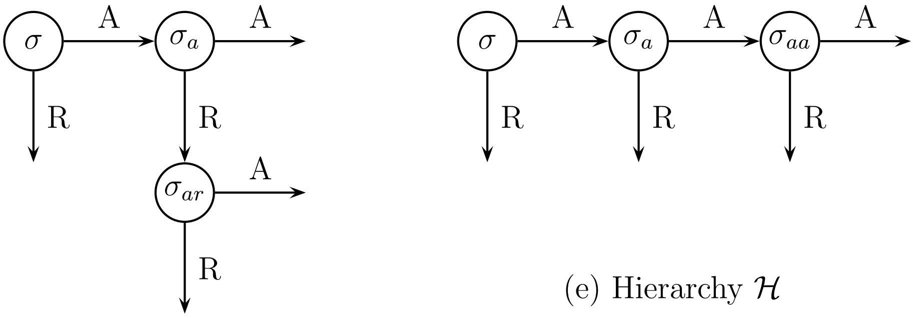
[1] Others who have followed the lead of Sah and Stiglitz include Koh (1992a, 1992b, 1994), Ioannides (1987, 2003), and Gehrig et al. (2000). Students of small group communication emphasize the persistence of fallible human decision making, see, *e.g.*, Hirokawa and Scheerhorn (1986) and Gouran and Hirokawa (1986). See also Campbell (1958) in the realm of information processing.

[2] I use the terms hierarchy and polyarchy to be as explicit as possible on the relationship between the sequential decision structures I use and the ones used by Sah and Stiglitz.



(b) Hybrid $\mathcal{PH}$

(a) Polyarchy $\mathcal{P}$



(e) Hierarchy $\mathcal{H}$

(d) Hybrid $\mathcal{HP}$

Figure 1: The four organizational structures studied

represent the direction in which projects flow in the organizations. The label on an edge starting at a node is associated with the action taken at that node (A =acceptance, R =rejection). A node is indexed by the sequence of actions necessary to reach the node. For example, in the polyarchy $\mathcal{P}$, Figure 1 (a), the project lands on desk σ_{rr} after a sequence of two rejections. In section 2.1, I make clear why I limit analysis to these four structures. The hierarchy and the polyarchy are called 'pure' as all nodes are linked in the same way. The other two structures are called 'hybrid' as connections between nodes differ.

The problem of the designer is to assign agents to positions within a given structure and to choose a structure. Consider a given structure and four agents with given abilities. I say that an assignment is optimal if this assignment maximizes the expected payoff on implemented projects. To verify whether an assignment is optimal or not, the designer may need information about the qualities of the agents. If any assignment yields the same payoff, no information about the quality of the individual agents is necessary. It could also be that the designer needs to be able to rank the agents in terms of their abilities. I then say that ordinal information is needed to assign agents correctly. The more detailed information is needed to verify the correctness of an assignment, the more complex I will call the structure.[3]

Robustness measures the degree to which financial performance changes as a result of changes in the environment. This is captured by the probability with which an organization accepts a project, the derivative of expected payoffs with respect to the (summary) parameter characterizing the environment. The lower this probability is, the less susceptible performance is to changes in the environment, and the more robust the organization will be said to be.

There are three sets of results. Concerning complexity, the pure structures are of least complexity as they do not require any information about the agents to position them correctly. For a project to be implemented in a hierarchy, it has to pass all three desks. Hence, the probability with which a project is implemented equals the product

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[3] In section 2.5, I discuss the relationship between this definition of complexity and the one used in the management literature on organizational design.

of individual probabilities of acceptance. In a polyarchy, rejection by the organization as a whole requires rejection by all members. Once again, the order does not matter. The hybrid structures $\mathcal{PH}$ and $\mathcal{HP}$ require ordinal information and are therefore more complex. Note that once a project has passed the first desk, it moves on to a structure which is really a two person hierarchy or polyarchy, respectively. At this point the order of agents is immaterial. The agent located at the first node, making as it were a pre–selection, should be the best. In a $\mathcal{PH}$, the first agent's review could be final and lead directly to project implementation, without being subjected to the tight screening offered by the hierarchical part of the structure. This first screening should therefore be the best. In a $\mathcal{HP}$, as the projects selected by the first agent will be subject to a rather loose screening of the consecutive polyarchical part of the structure, the first selection should be performed by the most able agent. These results show that differences in informational requirements, and therefore in organizational complexity, parallel differences in structural connections.

The second set of results deals with payoff performance. Which structure performs best depends on the type of environment. Both a polyarchy and a $\mathcal{PH}$ give rejected projects a 'second life' – one rejection is not final. This is optimal when the pool of projects is quite good (i.e., profitable projects are relatively abundant and/or possible profits are relatively high compared to possible losses). Among these two structures, the first has the more lenient implementation rule: after the first rejection, and even after the second, implementation only requires acceptance by one agent. This is therefore best only in the most friendly environments. In a hierarchy and a $\mathcal{HP}$, accepted projects are given a 'second look' when the sample is not so good to warrant the loose polyarchical review. The hierarchy is the tighter structure of the two, making it the better organization in more hostile environments.

It is always one of the *least* complex structures, the hierarchy or the polyarchy, that performs worst (the hierarchy when the environment is friendly; the polyarchy in case of a hostile environment). The reason is that the $\mathcal{PH}$ and $\mathcal{HP}$ structures combine structural features of both a hierarchy and a polyarchy. These structures can therefore improve upon whatever is the worst performing of the hierarchy and the polyarchy. In other words, the hierarchy and the polyarchy are highly geared towards a special type of environment, and quickly loose their attractiveness in other environments.

The third set of results deals with robustness. It is not hard to see that the polyarchy is the least robust, the $\mathcal{PH}$ is next, followed by the $\mathcal{HP}$, while the hierarchy is most robust. This follows from the definition of external robustness as the probability of acceptance.

These findings suggest a number of trade-offs in organizational design. Compared with a polyarchy, the hybrid structures are more profitable in many environments, and they are more robust. However, they also require more detailed information, information the designer may not have. The hybrid structures loose one advantage when compared with the hierarchy as the latter structure is more robust. However, the hierarchy performs badly in environments which are not very hostile.

There is a number of papers that is related to the present study. Ioannides (1987, 2003) applies findings from information theory to sequential decision structures to show that one can increase the performance of some organizations by a special type of replication called composition. Composition means that one replaces an individual agent by a replica of the entire organization. In this way, one can arbitrarily increase the probability of acceptance of good projects and, at the same time, reduce the probability of acceptance of bad projects. Such organizations will be very complicated and large. Reiter (1996) models organizations that are populated by agents whose communication and computation skills are limited. The organizational structure is a decision variable as the structure influences whether a desirable decision can be taken by the organization as a whole. The measure of complexity used is akin to the degree of composition. Within the realm of qualified majority decision rules, Ben–Yashar and Nitzan (2001) study the robustness of optimal decision rules. Robustness is measured by the maximal change in the total number of agents that does not alter the optimal qualified majority. They establish that, in general, such decision rules are not very robust. In particular, neither the hierarchy and the polyarchy are very robust according to this measure.[4]

In the next section, I introduce the model and the main concepts used. Section 3 presents the main results. Section 4 concludes. Proofs can be found in the Appendix.

2 The Model and Concepts Used

2.1 The Project Environment

A project can be either of good quality, $q = g$ (which is the case with probability α) or of bad quality, $q = b$. An implemented, good project gives rise to a profit X,

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[4] Note that a hierarchy implements projects with the same probability as a majority voting rule requiring acceptance by all, whereas polyarchies behave like a voting rule requiring acceptance by just one agent for a project to be implemented.

while an implemented, bad project leads to a loss equal to $-Y$. It will be useful to summarise the state of the environment by $\beta := \frac{1-\alpha}{\alpha}\frac{Y}{X}$. The higher β, the tougher the environment. This means that either possible losses rise relative to potential profits, or that bad projects become predominant.

2.2 The Agents

There are three agents $i \in \{1, 2, 3\}$. Let I be this set of agents. Each agent can either accept, A, or reject, R, a project. Ideally, one would like the agents to accept all good projects and to reject all bad projects. However, following Sah and Stiglitz (1986) I assume that every agent i is fallible. In particular, let p_i^b (p_i^g) stand for the probability with which agent i accepts bad (good) projects. I assume that: $0 < p_i^b < 1/2 < p_i^g < 1$. In words, agents accept bad projects, reject good ones, but do so less frequently than a randomizing device that accepts one out of two projects. Agent i will be called better at distinguishing good from bad projects than agent j if $p_i^g > p_j^g$ and $p_i^b < p_j^b$. This will be denoted by $i \succ j$.

Assumption 1 *The agents $i \in I$ are ordered:* $1 \succ 2 \succ 3$.

This assumption excludes discussion of situations in which an agent i accepts both more good *and* more bad projects than agent j. Moreover, the possibility of identical agents is ignored. Let T be the set of profiles of $\{(p_1^g, p_1^b), (p_2^g, p_2^b), (p_3^g, p_3^b)\}$.

One interpretation, offered by Sah and Stiglitz (1986), of the behavioural assumption is that agents receive a binary signal and have a decision rule that is exogenously fixed and does not depend on their position in the decision structure. As this paper is concerned with an analysis of the relationships between complexity, robustness, and performance, I feel that the simplicity of the behaviour implied by this assumption is acceptable. It is the simplest model I am aware of that allows for heterogeneity of agents. Alternatively, one could view the agents as tests that are run by various departments to check the viability of a product. The errors they make are then simply statistical type I and type II errors, and it seems quite plausible that the quality of individual tests does not depend on tests run by other parts of the organization.

2.3 Organizations

An organization characterizes both a structure Σ and an assignment ϕ.

Definition 1 *An* organization *is a pair* (Σ, ϕ)*. The* structures $\Sigma \in \{\mathcal{P}, \mathcal{PH}, \mathcal{HP}, \mathcal{H}\}$ *are depicted in Figure 1. An* assignment ϕ *is a mapping from the set of agents* I *to the set of positions in* Σ*. Let* $\mathcal{S}$ *be the set of structures.*

A structure fixes the flow of projects. The nodes in the structure are indexed by the sequence of decisions necessary to reach the node, *e.g.*, σ_{ar} is reached after first an acceptance at the root and a rejection at node σ_a. For every structure Σ, an assignment ϕ places agents 1, 2 and 3 at a desk. For a given structure let Φ be the set of possible assignments of agents to nodes.

I limit analysis to these four structures for various reasons. First of all, by limiting myself to structures with an equal number of nodes, and by assuming that agents are paid the same wage irrespective of the organization they work for, I can ignore the total wage bill in profit comparisons. Secondly, as will become clear below, three agents is the minimal number required to make a discussion of complexity interesting. Thirdly, the two structures I add have in common with the hierarchy and polyarchy introduced by Sah and Stiglitz that decisions are taken sequentially, that one person is the first to analyse any project, and that an agent can either reject or accept a project. In the language of graph theory, analysis is limited to the class of binary directed rooted trees of three nodes. I call the polyarchy and hierarchy 'pure' structures. Structures $\mathcal{PH}$ and $\mathcal{HP}$ are 'hybrid' structures, as they combine in some sense characteristics of both pure structures.[5]

An organization (Σ, ϕ) accepts projects of quality q with probability $p^q(\Sigma, \phi)$. The organizational structure fixes the functional *form* of $p(\Sigma, \phi)$, the same for both good and bad projects. Its precise *value* depends on the assignment ϕ, the characteristics of the agents, and the type of project q. The functional forms of $p(\Sigma, \phi)$ for $\Sigma \in \{\mathcal{P}, \mathcal{PH}, \mathcal{HP}, \mathcal{H}\}$ are as follows:

$$\begin{array}{lll} p(\sigma) + (1 - p(\sigma))[p(\sigma_r) + (1 - p(\sigma_r))p(\sigma_{rr})] & \text{if} & \Sigma = \mathcal{P} \\ p(\sigma) + (1 - p(\sigma))p(\sigma_r)p(\sigma_{ra}) & \text{if} & \Sigma = \mathcal{PH} \\ p(\sigma)[p(\sigma_a) + (1 - p(\sigma_a))p(\sigma_{ar})] & \text{if} & \Sigma = \mathcal{HP} \\ p(\sigma)p(\sigma_a)p(\sigma_{aa}) & \text{if} & \Sigma = \mathcal{H} \end{array} \tag{1}$$

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[5] A fifth possible structure in the class of binary directed rooted trees of three nodes works as follows. A first person decides whether to accept a project or not. If the project is accepted, it moves on to a second agent, while if it is rejected it is analysed by a third agent. The organization implements a project if one of the latter agents accepts it. I showed in a previous version of the paper that this structure is always outperformed by one of the four considered in the text. I therefore exclude it from consideration.

2.4 Organizational Performance

Organizational performance is measured by the expected value of an implemented project, $\alpha X p^g(\Sigma, \phi) - (1-\alpha) Y p^b(\Sigma, \phi)$. It will be useful to work with a monotone transformation of this expression:

$$V(\Sigma, \phi; \beta) = p^g(\Sigma, \phi) - \beta p^b(\Sigma, \phi) \tag{2}$$

An assignment ϕ such that, say, $(\phi(1), \phi(2), \phi(3)) = (\sigma_r, \sigma, \sigma_{ra})$ in the $\mathcal{PH}$ leads to a profit of $V(\Sigma, \phi; \beta) = p_2^g + (1-p_2^g)[p_1^g p_3^g] - \beta \left(p_2^b + (1-p_2^b)[p_1^b p_3^b]\right)$.

For a given structure Σ and agents with characteristics profile t, the designer is interested in finding an assignment that maximizes $V(\Sigma, \phi; \beta)$. Let $C : \mathcal{S} \times T \to \Phi$ be the correspondence such that $C(\Sigma, t)$ is the set of optimal assignments given the structure Σ and profile t.

2.5 Knowledge, Complexity, and Robustness

The organizational designer may not have the required level of detail of information to determine the optimal assignment. For a given Σ, say that

1. no information is needed to determine the optimal assignments if $C(\Sigma, t)$ is the same for all $t \in T$;

2. ordinal information is needed to determine the optimal assignments if, the preceding condition does not hold, but for any two profiles t and t' such that the agents have the same ordinal ranking, $C(\Sigma, t) = C(\Sigma, t')$

These informational requirements induce an ordering on the set of structures in terms of their complexity. The more information is required, the more complex the structure will be called.

The way I use ‘complexity’ is different from the way it is used in the literature on organizational design. There, a structure is called complex if it is made up of a large number of divisions or hierarchical layers or if it contains many interdependent parts the individual functioning of which is of importance to the overall performance of the organization. That is, organization theory presents complexity as an objective property of the organization, much in the same way as, e.g., its degree of centralisation. The claim is that the larger is the number of layers or divisions and the more intricate their interdependence, the more pressing the informational demands on organizational members and designer alike.[6] Given the interest in the informational demands, it only seems natural to express complexity of a structure in terms of and identify it with its demands on human cognition. A structure is not difficult, complicated or complex of itself, but from the designer’s perspective and relative to a problem he faces. This paper shows that differences in level of detail of information required in the optimisation problem parallel differences in type of structural connections between agents. It is not my aim to claim that the particular way of measuring or operationalizing complexity used in this paper is the only one possible. Rather, the gist of the paper is that a notion of structural complexity should be cognitive in nature, and defined relative to a specific problem at hand. It is then only logical that the specifics of measurement

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[6] See for example Galbraith (1973, 1977), Huber and Daft (1987), Jablin (1987), Lawrence and Lorsch (1967), Scott (1998), and Thompson (1967).

change with the problem under study.[7]

In the introduction I noticed that an environment that ‘changes’ and is ‘volatile’ is a major and growing concern for managers. Change makes the environment more difficult to operate in. In the present model, this means an environment that grows tougher, *i.e.*, a β that increases in value. I will say that an organization is robust to changes in the environment if its performance does not change much due to such changes. One way of operationalising robustness is by defining it as the derivative of expected profits $V(\Sigma, \phi; \beta)$ with respect to β.[8]

Definition 2 *The robustness of an organization* (Σ, ϕ) *equals* $R(\Sigma, \phi) = -p^b(\Sigma, \phi)$*. The more negative this number is, the less robust the organization is.*

It should be noted that an organization that is robust according to this definition could also be called conservative. The more robust an organization is, the less able it is to turn an improvement in the environment into profit.

3 Results

This section presents the findings concerning complexity, performance and robustness. It concludes with a discussion of the trade-offs in organizational design.

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[7] For further analysis of this point, see Fioretti and Visser (2004).

[8] I do not use an elasticity to measure the organization’s robustness as the units of measurement do not change from one structure to the other.

Complexity

Proposition 1 *The structures $\mathcal{P}$ and $\mathcal{H}$ are the least complex as no information is needed to determine the optimal assignments: $C(\mathcal{P}, t) = \Phi$ and $C(\mathcal{H}, t) = \Phi$ for all $t \in T$. The structures $\mathcal{PH}$ and $\mathcal{HP}$ are more complex as ordinal information is needed to determine the optimal assignments: the best agent, agent 1, should be located at the root. The order of agents 2 and 3 at the remaining nodes is immaterial.*

I provide the proof here. In the hierarchy, the functional form of $p(\mathcal{H}, \phi)$ equals $p(\sigma)p(\sigma_a)p(\sigma_{aa})$, see equation (1). The value of this product is left unaffected by changes in the assignment. The same holds for the polyarchy. This can best be understood by rewriting the functional form of $p(\mathcal{P}, \phi)$ as $1-(1-p(\sigma))(1-p(\sigma_r))(1-p(\sigma_{rr}))$, which is one minus the probability that a polyarchy rejects a project. Once again, the assignment leaves the probability of implementation unchanged.

Now consider $\mathcal{HP}$. I show that $C(\mathcal{HP}, t) = \{(\sigma, \sigma_a, \sigma_{ar}), (\sigma, \sigma_{ar}, \sigma_a)\}$ and that ordinal information is needed to determine these optimal assignments. First observe that interchanging the position of *any* pair of agents initially assigned to σ_a and σ_{ar} respectively, leaves the probability of implementation unchanged: the 'substructure' that starts at σ_a is a two–node polyarchy in which the order is immaterial. This means that if I have shown that $(\sigma, \sigma_a, \sigma_{ar}) \in C(\mathcal{HP}, t)$ then I have also proved that $(\sigma, \sigma_{ar}, \sigma_a) \in C(\mathcal{HP}, t)$.

Now consider the assignment $(\sigma, \sigma_a, \sigma_{ar})$, and call this the initial assignment. The probability of acceptance equals $p_1^q[p_2^q + (1 - p_2^q)p_3^q]$. Switching agents 1 and 2, gives rise to a new assignment with a probability of acceptance of $p_2^q[p_1^q + (1 - p_1^q)p_3^q]$. The difference in probability between initial and new assignment becomes

$$p_1^q[p_2^q + (1 - p_2^q)p_3^q] - p_2^q[p_1^q + (1 - p_1^q)p_3^q] = (p_1^q - p_2^q)p_3^q \tag{3}$$

This difference is positive for good projects and negative for bad projects, see Assumption 1, implying that the initial assignment is the better of the two. The selection of projects accepted at node σ_{ar} would deteriorate if one were to replace the initial assignment by the new one. Similarly, the selection of projects accepted at node σ_a worsens by switching agents 1 and 3, as can be seen from the difference in probability between initial and new assignment

$$(p_1^q - p_3^q)p_2^q \tag{4}$$

The above implies that the initial assignment $(\sigma, \sigma_a, \sigma_{ar})$ is optimal. And therefore so is $(\sigma, \sigma_{ar}, \sigma_a)$. That only the ordinal ranking of agents matters, and not the exact probabilities with which a project is accepted follows immediately from equations (3) and (4). Any change in the probabilities of acceptance of agents 1, 2 and 3 satisfying Assumption 1 leaves the sign of the expressions in these equations unaffected. That is, ordinal information is necessary and sufficient.

A similar line of reasoning shows that $C(\mathcal{PH}, t) = \{(\sigma, \sigma_r, \sigma_{ra}), (\sigma, \sigma_{ra}, \sigma_r)\}$ and that ordinal information is needed to determine these optimal assignments. [9]

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[9] In footnote 6, I described a fifth possible structure. For that structure cardinal information is needed to determine the optimal assignment. That is, ordinal information is not sufficient. Rather, the designer has to know the exact abilities of the agents.

Performance

In this subsection I will assume agents have been correctly assigned using Proposition 1 and compare the ensuing expected profits of the four structures. The next proposition shows that the polyarchy $\mathcal{P}$ is the better organization in very friendly environments, the $\mathcal{PH}$ in environments that are mildly friendly, the $\mathcal{HP}$ in moderately tough environments, and the hierarchy $\mathcal{H}$ in the tougher environments.

Proposition 2 *Let* $\phi^*(\Sigma) \in C(\Sigma, t)$ *for* $\Sigma \in \mathcal{S}$ *and* $t \in T$. *For every profile* $t \in T$, *there are values* $\beta_1(t) < \beta_2(t) < \beta_3(t)$ *such that*

$$\begin{aligned} \mathcal{P} &= \arg\max_{\Sigma} V(\Sigma, \phi^*(\Sigma); \beta) && \text{for } \beta < \beta_1(t) \\ \mathcal{PH} &= \arg\max_{\Sigma} V(\Sigma, \phi^*(\Sigma); \beta) && \text{for } \beta_1(t) < \beta < \beta_2(t) \\ \mathcal{HP} &= \arg\max_{\Sigma} V(\Sigma, \phi^*(\Sigma); \beta) && \text{for } \beta_2(t) < \beta < \beta_3(t) \\ \mathcal{H} &= \arg\max_{\Sigma} V(\Sigma, \phi^*(\Sigma); \beta) && \text{for } \beta > \beta_3(t) \end{aligned} \tag{5}$$

The proof can be found in the Appendix. The proposition is illustrated in Figure 2. In a polyarchy, a single acceptance is sufficient for project implementation, even after one or two rejections. This is best only in very friendly environments, i.e., environments in which good projects abound and/or profits X are high relative to possible losses Y. A hybrid $\mathcal{PH}$ still allows the first agent's acceptance to lead to implementation, but a rejection by the first agent now requires both the second and the third agent to accept the project. This is therefore best in moderately friendly environments. A hybrid $\mathcal{HP}$ even excludes the possibility that acceptance by a single agent leads to implementation. However, after the first acceptance, only one more acceptance is required for a project

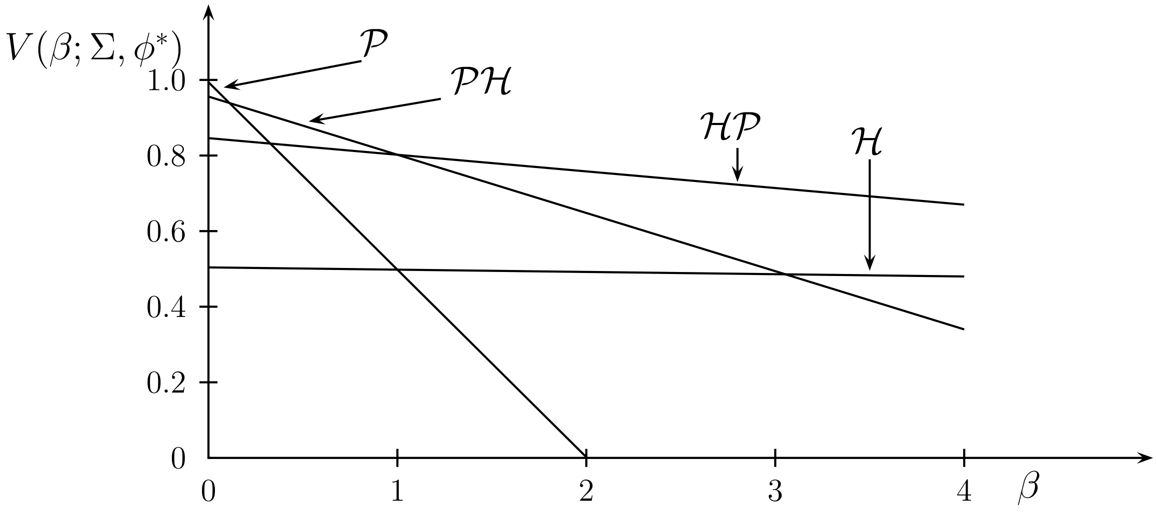

Figure 2: The expected pay–offs of the four organizational structures studied, with the profile $t = (0.9, 0.1), (0.8, 0.2), (0.7, 0.3)$.

to be implemented. Because of this feature, this structure is best in moderately tough environments. The pure hierarchy is the most demanding structure, requiring triple acceptance. It performs best in tough environments.

Robustness

Recall that the robustness of an organization is measured by $-p^b(\Sigma, \phi)$. The lower is this number, the lower is the organization's robustness. The following proposition states that the polyarchy is the least robust organization, followed by the $\mathcal{PH}$, then the $\mathcal{HP}$, while the hierarchy is the most robust.

Proposition 3 *Let* $\phi^*(\Sigma) \in C(\Sigma, t)$ *for* $\Sigma \in \mathcal{S}$ *and* $t \in T$. *Then,*

$$R(\mathcal{P}, \phi^*(\mathcal{P})) < R(\mathcal{PH}, \phi^*(\mathcal{PH})) < R(\mathcal{HP}, \phi^*(\mathcal{HP})) < R(\mathcal{H}, \phi^*(\mathcal{H})) \tag{6}$$

This result can be seen from Figure 1, as the robustness of an organization equals the slope of the expected profit curves.

Trade-offs

The results point to a number of trade-offs. A polyarchy requires no information to find the best assignment of agents and is optimal in very friendly environments, but its superiority heavily depends on this environment. Changes in the environment lead to relatively large changes in its performance. The hybrid structures are more robust, and perform fairly well in different environments, but they require more detailed information about the quality of the agents. Finally, the hierarchy is very robust because of its triple acceptance rule, and it performs best in tough environments. Moreover, no information about the agents is needed to assign them correctly. The only concern is that in many 'not so tough' environments it is outperformed by the hybrid $\mathcal{HP}$, if not by all other structures. In fact, it can be shown that it is either the hierarchy or the polyarchy, i.e., an organization of least complexity, that performs the worst among the four organizations, see also Figure 2.

If it is hard to identify the better of the three agents, it is even harder to ascertain their exact abilities. Such, however, is needed to identify the best organization for a given environment, see Proposition 2. Again, (a moderate degree of) robustness is a desirable characteristic for a structure to have.

If the designer is not sure about whether she attains maximum performance, she faces a difficult choice. Should she improve her knowledge of the agents, improve the quality of the agents, simplify the structure of the organization, influence the environment, or undertake a combination of these things?

4 Conclusion

This paper has illustrated how one could approach the relationship between organizational complexity, robustness, and performance. Complexity, defined as the level of detail of information needed to correctly allocate agents within an organizational structure, and robustness, defined as the degree to which organizational performance is left unchanged by changes in the environment, prove useful categories to distinguish organizational structures. The paper has also discussed a number of trade-offs an organizational designer faces.

The aim of this paper was to define these concepts and make a first analysis of their relationship. It points to some possible lines of future research. First of all, it is worthwhile to study models in which the behaviour of an agent is richer. If his behaviour is influenced by the position within the structure, the designer has to take into account an additional dimension when considering whether to swap the positions of two agents. Second, it would be worthwhile to extend the present analysis to structures in which a project can enter the organization at more than one point. Finally, it would be worthwhile to have more than casual evidence that complexity considerations as defined in this paper play a role in organizational design.

Appendix

Proof of Propositiont 2 As this result involves a general statement about a seven dimensional parameter–space ($(\overline{p}^b, \overline{p}^g)$ and β) involving five different structures providing an analytical proof is hard for the following reason. Fix values for $(\overline{p}^b, \overline{p}^g)$ and calculate for every pair of organizations the 'pivotal' value of β at which this pair performs equally well. In the statement of the result I mention three such values, β_i, $i = 1, 2, 3$. The 'less strict' organization always performs better for values of β lower than the pivotal value, and vice versa. These pivotal values are ordered along the positive line–segment. The problem is that this ordering may change with certain changes in $(\overline{p}^b, \overline{p}^g)$. This makes it difficult to establish analytically whether $\beta_1 < \beta_2 < \beta_3$ holds for all $(\overline{p}^b, \overline{p}^g)$, and whether the omniarchy is better than any other structure for some values of the parameters. I have therefore taken recourse to numerical methods. There was no instance among the 27 million randomly chosen vectors such that the omniarchy performed better than all other structures. □

Proof of Proposition 3 As $R(\Sigma, \phi^*(\Sigma)) = -p^b(\Sigma, \phi)$, one can use the expressions given in Equation (1) to find that $R(\mathcal{P}, \phi^*(\mathcal{P})) < R(\mathcal{PH}, \phi^*(\mathcal{PH})) < R(\mathcal{HP}, \phi^*(\mathcal{HP})) < R(\mathcal{H}, \phi^*(\mathcal{H}))$ for a given profile t. □

References

R. Ben–Yashar and S. Nitzan (2001), The Robustness of Optimal Organizational

Architectures: A Note on Hierarchies and Polyarchies, *Social Choice and Welfare*, **18**, pp. 155–63.

G. Fioretti and B. Visser (2004), *A Cognitive Approach to Organizational Complexity.* Tinbergen Institute Discussion Paper TI 2004–033/1.

J. Galbraith (1973), *Designing Complex Organizations.* Reading, Mass.: Addison–Wesley.

J. Galbraith (1977), *Organization Design.* New York etc.: Mc Graw–Hill Book Company.

T. Gehrig, P. Regibeau, and K. Rockett (2000), Project Evaluation and Organizational Form, *Review of Economic Design*, **5**, pp. 177–199.

G.P. Huber and R.L. Daft (1987), *The Information Environments of Organizations*, pp. 130–64 in F.M. Jablin et al., *Handbook of Organizational Communication. An Interdisciplinary Perspective.* Newbury Park etc.: Sage Publications.

Y. M. Ioannides (1987), On the Architecture of Complex Organizations, *Economics Letters*, **25**, pp. 201–6.

Y. M. Ioannides (2003), *Complexity and Organizational Architecture*, Working Paper, Tufts University.

F.M. Jablin (1987), *Formal Organization Structure*, pp. 389–419 in F.M. Jablin et al., *Handbook of Organizational Communication. An Interdisciplinary Perspective.* Newbury Park etc.: Sage Publications.

W. T. H. Koh (1992a), Human Fallibility and Sequential Decision Making. Hierarchy versus Polyarchy, *Journal of Economic Behavior and Organization*, **18**, pp. 317–345.

W. T. H. Koh (1992b), Variable Evaluation Costs and the Design of Fallible Hierarchies and Polyarchies, *Economics Letters*, **38**, pp. 313–318.

W. T. H. Koh (1994), Making Decisions in Committees. A Human Fallibility Approach, *Journal of Economic Behavior and Organization*, **23**, pp. 195–214.

P. R. Lawrence and J. W. Lorsch (1967), Differentiation and Integration in Complex Organizations, *Administrative Science Quarterly*, **12**, pp. 1–30.

S. Reiter (1996), *Coordination and the Structure of Firms*, Discussion Paper 1121, Northwestern University.

R.K. Sah and J.E. Stiglitz (1985), Human Fallibility and Economic Organization, *American Economic Review*, **75**, pp. 292–79.

R.K. Sah and J.E. Stiglitz (1986), The Architecture of Economic Systems: Hierarchies and Polyarchies, *American Economic Review*, **76**, pp. 716–27.

W.R. Scott (1998), *Organizations: Rational, Natural, and Open Systems.* New Jersey etc.: Prentice Hall International.

J.D. Thompson (1967), *Organizations in Action. Social Science Bases of Administrative Theory.* New York etc.: Mc Graw–Hill Book Company.