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Organizational Design and Resource Evaluation

By

Michael Christensen and Thorbjørn Knudsen

Danish Research Unit for Industrial Dynamics

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Michael Christensen
Department of Marketing & Management
University of Southern Denmark
Campusvej 55, DK-5230 Odense M, Denmark

Thorbjørn Knudsen
Department of Marketing & Management
University of Southern Denmark
Campusvej 55, DK-5230 Odense M, Denmark
Tel: +45 6550 1000
Fax: +45 6615 5129
E-mail: tok@sam.sdu.dk

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Abstract:
A crucial problem of evaluating, discovering, and creating the value of resources remains at the center of the subject of business strategy. The present article draws on reliability theory to advance an analytical platform that can address part of this problem, the evaluation of resource value. Reliability theory offers a way to model managerial ability and to derive the evaluation properties of organizations, boards, teams and committees. It is shown how the problem of resource evaluation can be remedied by proper evaluation structures. An evaluation structure that is build out of a very few agents can achieve significant improvements. A simulation of the classical n-armed bandit problem shows how evaluation structures can help managers select innovations of better economic value.

Key words: Reliability theory, resource value
JEL Codes: D46, O31

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1 Introduction

The purpose of the present article is to provide a formal theoretical framework that is useful in thinking about managerial evaluation of resource value. We conceptualize the judgmental ability of managers in the reverse; the higher the ability, the less errors get made. Drawing on reliability theory, the judgmental ability of a manager can be expressed as the probability of making two forms of error, rejecting uses of high value (errors of omission) and accepting uses of poor value (errors of commission). Using this specification, we provide a way to model different levels of managerial ability and show how the effect of alternative evaluation structures can be extracted. Through examples, it is shown that an evaluation structure built out of a few agents can achieve significant improvements in joint evaluation of resource value. A simulation of the classical n-armed bandit problem shows how evaluation structures can help managers select resources of higher economic value.

We address a critical unsolved problem in the resource-based view (RBV) of strategy relating to the evaluation of resource value. The problem of evaluating resource value underlies both resource-picking and capability-building (Makadok, 2001). Firms create economic rents both from being more effective than their rivals in acquiring resources from the factor market (resource-picking) and in using existing resources in more effective ways (capability building). We suggest that the essence of both of these problems concern imperfections in judgmental ability.

In order to understand how managers search for resource value, we must understand the limits in managerial ability that constrain their search efforts. Both in the RBV (Moran & Ghoshal, 1999) and from a behavioral perspective (Levinthal & March, 1981; Nelson & Winter, 1982; Lant & Mezias, 1990), it has been recognized that limited rationality constrains the sample size of the alternatives considered. Thus managers consider a limited set of possible resources that can be acquired and they consider a limited set of ways that existing resources can be deployed. A more fundamental issue of limits constraining the manager's *ability* in evaluating the value of resources, once identified, has been given scant attention. As the many studies of entrepreneurship show, this problem of evaluating resource value is of critical importance both when alternative resources are picked and when alternative ways of deploying a resource are considered. Indeed, securing the best resources as well as securing the best use of the firm's resources are fundamental problems at the center of research in business strategy (Lippman & Rumelt, 2003a, 2003b; Makadok, 2001; Moran & Ghoshal, 1999). Resources are here defined broadly as all kinds of assets whose potential services can be used in production (Moran & Ghoshal, 1999).

The resource-based view (RBV) of strategy has mainly focussed on sustaining the competitive advantage in firms endowed with resources that have superior value. Indeed, the RBV is silent on antecedents to the composition of the firm's resource portfolio, even though in the earliest formulations of the theory (Penrose, 1959), managerial decision making on the composition of the firm's resource bundle is a central component of the theory. Even if a few exceptional recent contributions have made significant progress (in particular Makadok, 2001), a fundamental problem of explaining how differential resource value is attained remains unsolved in the RBV.

The RBV asserts that firms attain competitive advantage if they possess or control (e.g. patented) resources with superior value and sustain this advantage if the resources in question continue to be in limited supply (Lippman & Rumelt, 1982; Barney, 1986, 1991; Dierickx & Cool, 1989; Conner, 1991; Peteraf, 1993; Lippman & Rumelt, 2003a, 2003b). Most efforts in this line of research have been directed towards the identification of conditions that *sustain* the value of a bundle of resources, i.e., limits to imitation and substitution of valuable resources (Barney, 1991; Peteraf, 1993). These conditions secure limited diffusion of valuable resources – or functional equivalents – into industry. More recent refinements have extended these conditions to encompass combinations of common resources that are co-specialized with resources in limited supply (Lippman & Rumelt, 2003a, 2003b). Less is known about the ways in which a firm *attains* and *develops* a valuable bundle of resources, i.e. why some firms end acquire more valuable resources than their rivals (and divest less valuable resources) and why some firms deploy resources in ways that create more value than other firms do with similar resources.

A possible source of heterogeneity is the many ways a particular resource (e.g. land) can be deployed (various crops are available, various alternatives may exist such as the building of a holiday resort). A well-known industrial example is the accidental combination of chemicals leading to the discovery of adhesive by 3M scientists (Moran & Ghoshal, 1999). Indeed, new combinations of chemicals are today generated and evaluated in a systematic way in order to enhance exploration of new useful adhesives (Jones-Bey, 2004). Firms explore new combinations of using their resources. If there are vast possibilities of using a resource, and there usually are, some firms might well discover high value in particular uses while other firms find little value. This effect is further augmented by considering new ways of combining resources (both human and physical). The argument is that differential managerial ability lies at the root of the differences in the value of deploying resource bundles that are accumulated by firms. Similar problems of evaluation underlie and blends with the assessment of value of resources that are acquired in factor markets, such as the hiring of new employees.

We are here extending and complementing Makadok's (2001) recent work in suggesting that the problem of evaluating resource value underlies both resource-picking and capability-building. In essence, we find that evaluation is an important determinant of differential value reaped in use of resources and thus of firm level resource heterogeneity. A similar argument (even though not developed in detail here) applies to differential ability in picking resources. The wider implication for the RBV is that we outline the contours of an explanation of the underlying sources of heterogeneity (Lippman & Rumelt, 2003b; Peteraf & Bergen, 2003).

Limits to managerial ability lies at the root of the RBV as it does in theories of entrepreneurship (Baumol, 2002). The issue shows up also in the large body of literature on transaction cost economics (Williamson, 1975, 1985) and the property rights approach (Grossman & Hart, 1986; Hart & Moore, 1990). Whereas managerial ability is an independent variable in the RBV and in the literature on entrepreneurship, it is a dependent variable in the contractarian approaches. In the RBV, ability is a determinant of managerial search and therefore the value of the resource bundles that firms accumulate and the valuable uses that they discover. By contrast, incentive problems give rise to misdirected actions and less effort than may be wished for. Contractarian approaches are invaluable in identifying the situations in which incentive problems arise and the remedies that may alleviate such problems (see Makadok, 2001, 2003 for a treatment of incentive problems). When incentive problems are remedied, less error get made and the managerial ability effectively increases. In the following, we abstract from incentive problems, in order to focus on the issue of managerial ability.

The article is organized in the following way. Section 2 develops the model of individual level managerial ability, section 3 shows how evaluation structures can be designed to enhance individual level managerial ability, section 4 uses the n-armed bandit problem to show how evaluation structures may benefit managerial search, and section 5 outlines implications for research. Section 6 concludes the article.

2 Discovery of resource value

To maintain focus and clarity of exposition, the present article is concerned with the discovery of resource value in deployment of resources. The evaluation perspective developed here can be extended in a straightforward manner to the problem of evaluating resources that are acquired in factor markets. A detailed treatment of this topic is left for future work.

The discovery of resource value involves better use of existing resources as well as the classical case of innovation, defined as the combination of resources in novel ways (Moran & Ghoshal, 1999; Schumpeter, 1934). A manager chooses among possible uses of a resource (e.g. chemical compounds or land) on the basis of an imperfect evaluation of the value of these possible uses. This evaluation may include activities associated with innovation (Moran & Ghoshal, 1999), such as the consideration of uses where resources are combined with other resources in novel ways (e.g. new chemical compounds or land in combination with new crops). Even though difficulties in discovery of resource value arise from various specific causes (such as imperfect information about the uses of a particular resource and the way resources can be combined in use), there is a general problem of designing organizations that can mitigate the consequences of imperfect evaluation.

The present article provides a formal analytical platform that is useful in tackling specific design problems as regards evaluation of resource value. In our formal model, the possible uses of a resource is captured in a random variable $\tilde{\mathbf{x}}$. Each use is represented by a vector of perfect signals, $\mathbf{x}$, about its quality, capturing all of the elements that are of relevance if the manager accepts a particular use of a resource.

The vector of perfect signals maps onto a scalar economic value, $y = \mathcal{P}(\mathbf{x})$, a net income that is obtained by the manager if a particular use is chosen. This scalar valuation is the value-in-use of a resource, including all of the relevant benefits and costs. The costs of making the decision is not included in the income because it is endogenous to the evaluation process. The costs of making the decision depends on the size of the evaluation structure (the number of agents involved in evaluation), the levels of pay, the choice of compensation method (e.g. fixed salary or pay per evaluation), and the possibility of economies of scale with respect to evaluation.

Drawing on the standard search model, dating back to Stigler (1962), Lippman & Rumelt (2003b) illustrate a possible way of modelling the discovery of resource value. Define the cumulative distribution $H(y)$ of values in use, $y = \mathcal{P}(\mathbf{x})$. The cost of examining a new use is $k > 0$, and a fixed reservation value, ξ, determines when search stops. The reservation value, ξ, satisfies

$$k = \int_{\xi}^{\infty} (y - \xi) dH(y) \tag{1}$$

Assuming that the manager makes no errors of judgement, more productive search of profitable uses can simply be expressed as a smaller inspection cost (Lippman & Rumelt, 2003b). In this case, a manager with a smaller inspection cost (k), has a larger reservation value (ξ) and therefore engages in more search for alternative uses. As a result, this manager has a greater expected net profit, and, on average, concludes search having located better alternative uses.

A lower inspection cost results in a larger sample of possible uses. This specification is consistent with the idea that limited rationality is expressed as limits to the size of the subset of alternatives that the agent is able to consider (Simon, 1955; 1956). Yet, deeper issues regarding the nature of managerial ability remain unanswered. First, the nature of the agent's sample process is ignored. It seems reasonable, however, to think of low managerial ability also in terms of a misguided sampling process. If a manager systematically searches in all the wrong places, a larger sample is not necessarily a blessing. Second, a more able manager might be thought of as being more creative. Within the parameters of the standard search model, creativity can be thought of as a transformation that shifts the distribution $H(y)$ towards more valuable uses. Third, the manager's ability to evaluate the value of alternative uses may be limited. The remainder of the article focusses on the evaluation problem and leaves the treatment of sampling processes and creativity to future work.

2.1 Managerial fallibility

We wish to address the problem of evaluating the alternative uses of a resource in the more realistic case where the manager makes errors of judgement. The ability of a manager can be expressed as the probability of making two forms of error, rejecting uses of high value (errors of omission) and accepting uses of poor value (errors of commission). Value is here the simple rent as defined by Lippman & Rumelt (2003a, 2003b). For a given cost per time unit of inspecting a possible use of a resource, the manager wishes to minimize both forms of error. If there is error in judgement of value, Equation 1 cannot be used.

The error has two effects. First, the manager will on average discover less valuable uses. Second, the manager's search activity is influenced. For a given inspection cost, k, a manager that makes an error of commission will stop search prematurely, and a manager that makes an error of omission will continue to search even if a use that meets the reservation value was found. The probability of stopping search, S, in the case where the evaluation is error-free is

$$P(S|y \geqslant \xi) = 1 \wedge P(S|y < \xi) = 0 \tag{2}$$

and the probability of stopping search in the case of imperfect evaluation is

$$P(S|y \geqslant \xi) < 1 \wedge P(S|y < \xi) > 0 \tag{3}$$

The individual manager's ability in evaluating the possible uses of a resource is conveniently expressed as the *agent screening* function, $f(\mathbf{x})$, which is a probability measure mapping each vector of signals about value-in-use onto a probability that the manager accepts a possible use of a resource and stops search.

An omniscient manager would not make a single error of judgment. Such a manager, Eric, is illustrated in Figure 1. Eric would process all of the perfect signals about the true value-in-use without noise. The omniscient manager, Eric, therefore stops search and accepts a possible use of a resource with the economic value $\mathcal{P}(\mathbf{x}) \geqslant \xi$ ($< \xi$) with probability $f(\mathbf{x}) = 1$ (0). That is to say, the agent screening function of the omniscient manager is $f_\Theta(\mathbf{x}) \equiv \Theta(\mathcal{P}(\mathbf{x}) - \xi)$, where Θ is the Heaviside step-function. In Figure 1, the reservation value, ξ, is set to 0, and Eric's screening function is the step-function that assigns zero probability to accepting a use with value below zero. Uses with values equal to or above zero is accepted with probability one.

All real managers are fallible; they occasionally make errors of judgment even though well-intentioned (Stiglitz, 2002). In finance, accounting and elsewhere (there are many references supporting this claim, too many to begin quoting), a commonly acknowledged source of such error is the variation in information quality. Signals are noisy. In the RBV, Makadok (2003), has used a similar conceptualization of information quality as noisy signals.

Using the common analogy from statistical inference, managers accept a possible use of a resource that should be rejected (Type II error) and they reject a possible use that should be accepted (Type I error). It is the limitations in the cognitive and sensory apparatus that makes the manager fallible; noise decreases the information that a manager can extract from a signal, which introduces error in judgment.

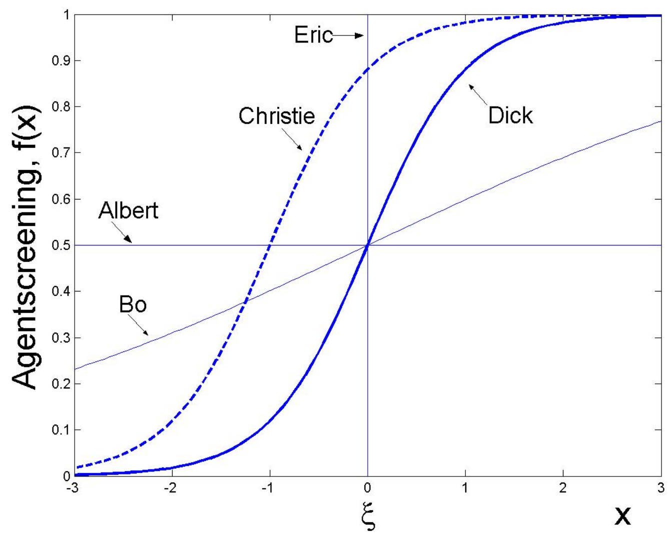

Figure 1: *Judgmental bias and different levels of discriminating ability.*

With noisy quality signals, the ability to pass judgment (about quality) is imperfect. That is, the discrimination between the value of alternative uses of a resource becomes uncertain with noise. In consequence, with very high levels of noise, it becomes difficult to tell which of the possible uses of a resource that is most valuable. In the most extreme case (a limit case that may not be reached in actual practice), the manager might completely loose the ability to discriminate; the manager simply processes signals about the value-in-use by flipping a coin, $f(\mathbf{x}) = 1/2$. The manager Albert in Figure 1 has no discriminating ability. In the case of noiseless processing (as in standard textbook exonomics), the manager has perfect discriminating ability; Eric is omniscient and assigns signals about value-in-use to acceptance or rejection of a particular use in a deterministic way. In the general case the level of noise in the manager's processing of signals is the measure

$$\int_{\mathbf{x}} |f_{\Theta}(\mathbf{x}) - f(\mathbf{x})|\, d\mathbf{x}. \tag{4}$$

In particular cases, it is useful to make a distinction between noise and bias. Bias is a deviation from symmetry in agent screening, whereas noise is captured in the slope of the screening function (Ben-Yashar & Nitzan, 1997). In Figure 1 the level of judgmental ability (captured in the slope of the screening function) increases from Albert the coin-flipper to Eric the perfect evaluator. Thus, Albert, Bo, Dick and

Eric have different levels of *unbiased* judgmental ability. By contrast, the manager Christie suffers from a judgmental bias even if her judgmental ability is generally high. Christie's judgmental ability is equal to Dick's, but her optimistic bias leads her to accept uses even with values below the reservation value, ξ. If opportunities for uses were evenly distributed around ξ, Christie's business would do less well than Dick's. When there is a difference between the judgmental ability of two managers, holding constant the inspection cost, k, there is a difference in the economic result they will experience.

More generally, this difference in judgmental ability is a particularly important expression of asymmetric information, giving rise to heterogeneity in resource value as argued in the RBV (Barney, 1986, 1991; Peteraf, 1993; Foss & Knudsen, 2003; Lippman & Rumelt, 2003b). Absent fluctuations in the value-in-use, a more able manager will assemble resources of higher value and direct resources to more productive uses, a conclusion that is similar to Makadok's (2001). Thus higher judgmental ability can be a source of greater expected net profit. As shown in the following, however, a high level of fluctuations in resource value can lead to the counter-intuitive conclusion that a *less* able manager may enjoy greater expected net profit than a more able manager. Heterogeneity in resource value is a critical and so far unexplained assumption in the RBV (Barney, 1986, 1991; Peteraf, 1993; Lippman & Rumelt, 2003a).

The present article traces such heterogeneity to two sources, asymmetric information and complementarities, which aligns with Lippman & Rumelt's (2003b) analysis. In our analysis, asymmetric information arises from differential judgmental ability at the *individual level*. Complementarities, in contrast, arise from evaluation structures. As shown in the following, some evaluation structures will enhance, and others diminish, judgmental ability at the *organizational level* even though organization members have identical ability.

3 Enhancing judgmental ability through evaluation structures

A manager is located in an evaluation structure including n members. The task of the evaluation structure is to decide which uses of a resource to accept and which to reject. Its objective is to maximize income $\mathcal{P}(\mathbf{x})$ net of evaluation costs or, in some cases, to minimize the incidence of Type-I and Type-II error. The focus is shifted towards the latter objective in the case of evaluating the investments in resources that are critical because they can ruin the firm. In order to address issues of income maximization, we must first understand how the incidence of Type-I and Type-II error can be minimized. The present effort is therefore focussed on the design of reliable evaluation structures in the sense that they minimize the incidence of Type-I and Type-II error subject to the constraints of the number of available evaluators and their ability.

Note, in the case of perfect decision-making ability, the evaluation structure has no effect because not a single error is made; all possible uses of a resource that meet the reservation value would be accepted and other uses rejected. In all realistic cases errors get made (Stiglitz, 2002). Therefore, the problem of designing reliable evaluation structures is a critical issue in business strategy, both from a theoretical perspective and in practice.

3.1 From agent to evaluation structure

Consider a system of fallible managers that are *homogenous* in their decision-making ability. The source of error is noise in the processing of signals about the quality of a resource. Each individual manager has access to two distinct types of communication channels, one is used in the case that a resource (and its possible uses) is accepted and the other in case of rejection. It is the availability of both of these channels of communication that allow the evaluators to make the independent deliberate choices that are characteristic of human agents.

The evaluation structure is modelled as a graph. Each node represents a manager and each edge represents a channel of communication. We focus on homogenous graphs (one type of agent, A) with two types of edges (accept/reject). The entry and the exit of a resource are determined by the way the internal structure is connected to three external nodes: (1) the *initial portfolio* (**I**) containing the distribution of signals about the quality of resources $\tilde{\mathbf{x}}$, (2) the *final portfolio* (**F**) where the accepted ways of using a resource are implemented, and (3) the *termination* node (**T**) where the rejected ways of using a resource are dumped. The design of the evaluation structure involves the specification of the edges that connect members, the specification of the edges that connect the internal structure, through some of its members, to the external nodes (**I, F, T**), and the specification of the rules that determine how many times a member can evaluate the same project (a truncation rule).

The generalization of the agent screening function f to the level of a specific architecture G is the *graph screening* function F_G. The graph screening function is an aggregation rule that assigns individual decisions of acceptance and rejection to any structure. It can be viewed as a generalization of the aggregation rules that have previously been used to model decision-making in the case of committees (Ben-Yashar & Nitzan, 1997; Sah & Stiglitz, 1988). In mathematical reliability theory, the graph screening function is know as the system reliability (Lomnicki, 1973) or the reliability function of a network (Carlsson & Grenander, 1966).

It is often useful to express the graph screening in terms of a *reduced* graph screening function. In the case of homogenous ability, the graph screening function is a polynomial in $\alpha \equiv f(\mathbf{x})$ commonly known as the reliability polynomial.[1] An evaluation structure can improve the reliability of the decisions that get made. To see how, consider a hierarchical evaluation structure made of n agents. In a hierarchy,

[1] In the case of j levels of heterogeneous ability, $\alpha_j \equiv f_j(\mathbf{x})$, the graph screening function is a multinomial in α_j.

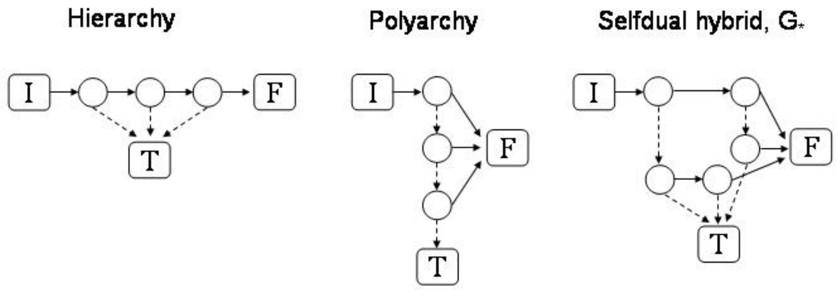

Figure 2: *Example of evaluation structures. A 3-member hierarchy, a 3-member polyarchy, and the self-dual graph G_* used to steepen the graph screening function. Full lines are acceptance edges and dashed lines are rejection edges.*

each agent can reject a possible use of a resource, but every agent must accept it before a final acceptance is reached in the structure. The evaluation structure is a polynomial and the screening function, or reliability polynomial, of the hierarchy is particularly simple. Its screening function is

$$F_{H_n}(\alpha) = \alpha^n \tag{5}$$

A flat evaluation structure, referred to as a polyarchy by Sah & Stiglitz (1988), is the exact opposite of the hierarchy. In a polyarchy, each agent can accept a possible use of a resource, but every agent must reject before a use is finally rejected by the structure. Its screening function is

$$F_{P_n}(\alpha) = 1 - (1 - \alpha)^n \tag{6}$$

It can be shown (Christensen & Knudsen, 2004), that finite hierarchies (polyarchies) map the agent screening of any project closer to 0 (1) than any other structure with the same number of agents (provided the agents are homogenous in ability). The implication is that hierarchies and polyarchies tend to reduce only one form of error.

3.2 Removing bias and improving the ability to discriminate

An evaluation structure can be designed to remove a bias or to improve the discriminating ability above the level of the individuals that are part of the structure. We first consider the removal of bias. The number of agents that are required to reduce the incidence of Type-I and Type-II error to some minimal desired level is provided below in Theorem 1. This result is useful for design purposes and follows trivially from the graph screening functions of the n-member hierarchy H_n (Equation 5) and polyarchy P_n (Equation 6)

Theorem 1
Given any threshold $0 < \delta < 1$ *and a point* $\alpha_0 \in]0, 1[$*, the number of agents* n *in a hierarchy such that* $F_{H_n}(\alpha) \leqslant \delta,\ \forall \alpha \in [0, \alpha_0]$*, is*

$$n \geqslant \frac{\log(\delta)}{\log(\alpha_0)} \tag{7}$$

and the number of agents n *in a polyarchy such that* $F_{P_n}(\alpha) \geqslant 1 - \delta,\ \forall \alpha \in [0, \alpha_0]$*, is*

$$n \geqslant \frac{\log(\delta)}{\log(1 - \alpha_0)} \tag{8}$$

We now illustrate how evaluation structures can be designed to minimize managerial fallibility and thus minimize the error in managerial search. It is useful to divide the procedure in two steps. Step one removes any bias in the screening function and step two further improves the discriminating ability of the unbiased screening function. Consider the biased screening function of Christie in Figure 1. In order to make things simple, the quality signal is a scalar, y, and Christie's screening function is

$$\alpha = f(y) = \frac{1 + \tanh(y + 1)}{2} \tag{9}$$

A CEO wants to employ an evaluator, but he knows that the available evaluators are too optimistic. Assume, the available evaluators have a screening function like Christie's. The CEO knows he must use a hierarchical structure to reduce or perhaps even remove the optimistic bias. How large should the hierarchy be? In Christie's case, $\xi = 0$ and $\alpha_0 = f(\xi) \sim 0.88$. By contrast, for an unbiased (imperfect) screening function $\alpha_0 = 0.50$. Assume that the CEO's target is to build a structure that achieves $F_{H_n}(\alpha) \leqslant \delta = 0.55$, i.e., the CEO accepts a tolerance of 10% from the target of the unbiased screening function of 0.50.

According to Theorem 1, the CEO finds that a hierarchy of $n \geqslant \log(\delta)/\log(\alpha_0) \sim \log(0.55)/\log(0.88) \sim 4.68$ will meet his target. A comparison of the four- and five-member hierarchy leads to the conclusion that the resulting unbiased evaluation structure is a hierarchy employing five evaluators, all with a bias similar to Christie's. The manager has designed an unbiased evaluation structure from biased members. Its screening function is shown in Figure 3. The unbiased evaluation structure is a source of competitive advantage for this manager. Should another manager for some reason decide to design a flat evaluation structure, it would have an even more severe optimistic bias than Christie's screening function. Clearly, this flat structure would be at a disadvantage if it competed against the five-member hierarchy. Note also, had Christie's bias been pessimistic, the manager should have chosen a flat, polyarchical structure to remove the bias. Evaluation structures are potential sources of advantage and disadvantage. For this reason, both researchers and practitioners gain from insights into their properties.

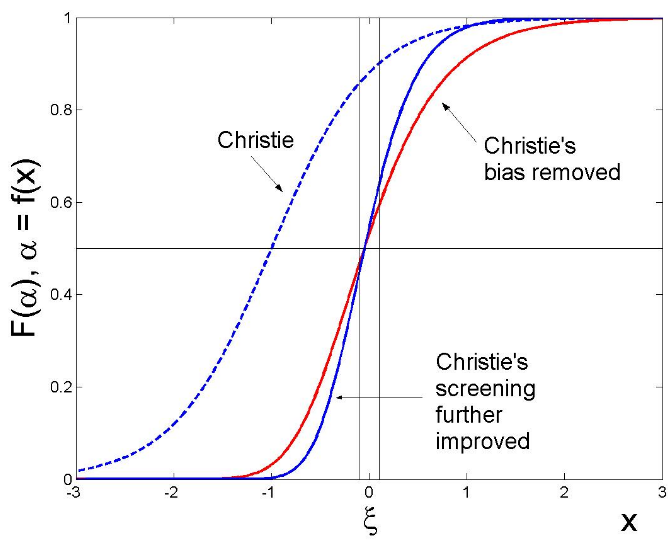

Figure 3: *Removal of bias and further improvement of judgmental ability.*

We have now shown how a bias that influences managerial evaluation can be removed such that the rate of Type I and Type II errors are balanced around the manager's reservation value, ξ. By choosing an appropriate design, including both hierarchical and polyarchical elements, it is possible to achieve further improvements that reduce both Type I and Type II error. In order to achieve this, the manager must use a so-called self-dual evaluation structure. Such an evaluation structure achieves a symmetric improvement of a screening function. It can be shown that the self-dual graph used here is the best choice if the manager will build a small evaluation structure (including less than 9 agents). In order to use the self-dual graph, the manager hires five unbiased evaluators and place them in the structure, G_*, as shown in Figure 2. If the only available evaluators are of Christie's type, another possibility is to design a structure where each of the nodes in the self-dual graph is a five-member hierarchy. As shown in Figure 3, Christie's unbiased screening function is further steepened. As a result, such managers make better evaluations of the value-in-use of resources than managers that use evaluators of similar ability on an individual basis. On average, they well select superior bundles of resources, which can serve as a basis for competitive advantage. In principle, the self-dual graph could be used repeatedly in order to approach perfect screening (Christensen & Knudsen, 2004). In principle, perfect reliability could be achieved. For each repeated use, the evaluation structure increases with a factor 5; very quickly, the evaluation structure would grow to unrealistic proportions. The important point, however, is that significant incremental improvements can be achieved even with a small number of agents.

4 How evaluation structures may benefit search

Managerial search is commonly thought of as the dilemma of balancing exploitation and exploration (Garcia, Calantone, Levine, 2003; Greve, 2003; March, 1991; Holmqvist, 2004). The manager has to *exploit* what is already known about the possible uses of a resource in order to obtain a pay-off, but he must also continue to *explore* in order to discover uses that may increase the pay-off (Sutton & Barto, 2000). The dilemma is that the manager must continue to pursue some balance of both actions in order to become successful. A variety of new possible uses (innovations) must be explored while progressively selecting and implementing the most promising (March, 1991; Sutton & Barto, 2000).

The canonical model of the exploration-exploitation dilemma is the n-armed bandit problem (Sutton & Barto, 2000). In this problem, a decision-maker is repeatedly faced with n possible actions. After each choice, the decision-maker receives a numerical pay-off that depends on the particular choice that was made. The task is to maximize the numerical pay-off. A common analogy is that of choosing among uses of alternative medical treatments with the aim of achieving better "performance" of patients (Sutton & Barto, 2000). In our case, the analogy is of a manager choosing among alternative resources in order to increase the economic performance of the firm. Exactly the same challenge is faced by the manager choosing among alternative uses of a single resource, e.g. an employee can work according to many different job specifications.

4.1 The model

As illustration, we chose one of the simplest ways of modelling managerial search. We used a simple n-armed bandit with $n = 11$ (robustness tests show that the results are qualitatively similar with different values of n). The expected values of the 11 arms were fixed and uniformly distributed as $\mathcal{P}_n = \{-5, ..., 5\}$. A population of 100 managers had a fixed inspection cost, k, allowing a sequence of inspections over 1000 time-steps. The search procedure follows the specification of Equation 1. Initially, the manager draws a possible use of a resource at random, an innovation with expected value μ_y. The expected value-in-use of a resource is constant, but the actual value fluctuates because of a random component, σ, in use-value. In a particular time-step, t, the actual value from the resource is $y_t = \mu_y \pm \sigma$.

Then, in each subsequent time-step, the manager also draws a possible alternative with an expected value-in-use of μ_z and an actual value of $z_t = \mu_z \pm \sigma$. On the basis of the difference in the observed values, $(z_t - y_t)$, the manager then estimates a point probability, $\alpha = f(z_t - y_t)$, that the new use z should be adopted. A random draw determines whether the manager decides to shift from resource y to resource z. If it happens that the manager continues to use y over t periods, he forms a more reliable estimate of its value. A common way to do this is by averaging the pay-offs actually received (Sutton & Barto, 2000)

$$\overline{y} = \frac{y_1 + y_2 + ... + y_t}{t} \tag{10}$$

As t becomes very large, the estimate, $\overline{y}$ converges to the expected value μ_y. The manager therefore uses $\overline{y}$ as the reservation value against which the new uses that he explores are compared. That is, the manager uses the point probability $\alpha = f(z_t - \overline{y})$ to decide whether he should drop y and adopt z. Whenever the manager decides to drop a use, y, he also remembers the estimate $\overline{y}$.

The whole point of the exercise is to examine how managerial fallibility in evaluation influences performance and how evaluation structures may help fallible managers improve performance. We model managerial fallibility as an imperfect screening of the difference in value of two uses of a resource, $\alpha = f(z_t - \overline{y})$. Perfect screening is sharp: whenever $z_t > \overline{y}$ $(z_t \leqslant \overline{y})$, the probability, α, of accepting z is 1(0). In the case of imperfect screening, $\alpha = f(z_t - \overline{y}) < 1$ (> 0) for some values of $z_t > \overline{y}$ $(z_t \leqslant \overline{y})$.

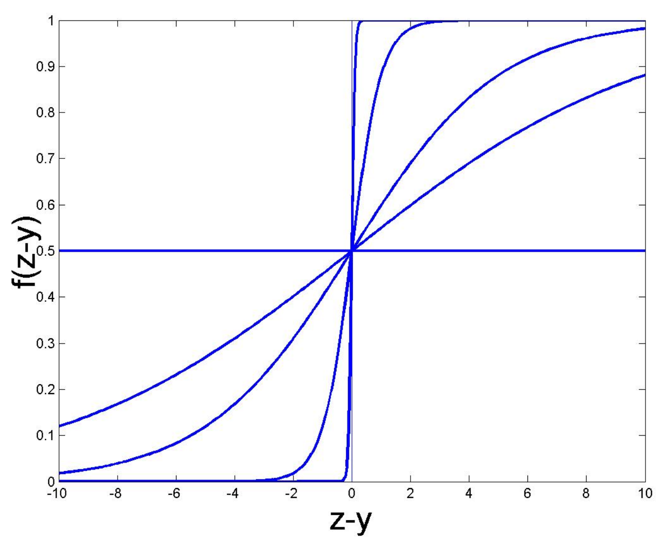

Figure 4: *The six levels of judgmental ability used in the simulation. The maximal difference in value was approximately* $\pm(10 + 6\sigma)$.

We examined six levels of managerial ability. The lowest level of ability was the case of Albert in Figure 1. Albert has no discriminating ability and simply processes signals about the value-in-use by flipping a coin, $f(z_t - \overline{y}) = 1/2$. That is, Albert accepts every new alternative with probability 1/2. The highest level of ability in evaluating differences of value-in-use was the case of Eric in Figure 1. Eric accepts a new alternative use, z, over an old use, y, with probability $f(z_t - \overline{y}) = 1$ (0) if $z_t > \overline{y}$ ($z_t \leqslant \overline{y}$). Four levels of managerial ability between Albert's and Eric's were modelled as

$$\alpha = f(z_t - \overline{y}) = \frac{1 + \tanh(j \cdot (z_t - \overline{y}))}{2} \tag{11}$$

for $j = \{1/10, 1/5, 1, 10\}$, where higher j is higher ability. The levels of managerial ability used in the simulation are shown in Figure 4. The economic effect of the level of ability depends on size of the differences, $z_t - \overline{y}$, that a manager will face. Almost all values fall within $\pm(5 + 3\,\sigma)$. Therefore, the maximal differences are approximately $\pm(10 + 6\,\sigma)$, where σ is the random component of value. A critical issue is whether the manager is able to distinguish between neighboring values, having a difference of 1. A standard variation of less than $\sigma = 1/3$ ensures that the manager in most cases can distinguish between neighboring values in this model. Similarly, a standard variation of less than $\sigma = 3$ ensures that the manager in most cases can distinguish between extreme values in this model. On this basis, we examined three levels of the random component in value, $\sigma = \{0.00, 0.30, 3.00\}$. A random component of $\sigma = 0$ provides a baseline model by removing any random fluctuation in value.

As mentioned above, the differences in judgmental ability can be divided into levels of unbiased evaluation and levels of bias. In addition to the examination of the unbiased screening, we examined two levels of positive and negative judgmental bias. A positive bias of, for example, 3 moves the point ($x = 0, f(x) = 1/2$) to ($x = 3, f(x) = 1/2$). We examined the effect of bias for each level of (unbiased) managerial ability, as defined in Equation 11. Simulations for two levels of positive bias (3, 10) and two levels of negative bias (-3, -10) are reported.

A simulation examined four populations of evaluation structures, each containing 100 members with identical managerial ability. The populations in question were: (1) single agents, (2) hierarchies, (3) polyarchies, and (4) hybrids containing both hierarchical and polyarchical elements. Figure 2 shows examples of a hierarchy, a polyarchy, and a hybrid. Whereas the population of single agents is well-defined, the sizes of the other evaluation structures were allowed to vary in size. The hierarchies had randomly generated sizes of between 2 and 10 members. The minimal size of a hierarchy is 2 and hierarchies with more than 10 members would be hard to find in practical applications. The population of polyarchies was generated in a similar way, such that it had random sizes between 2 and 10. The population of hybrids was generated by assigning a single agent plus a random number of members to random entries in a 5×5 grid. On average, the size of a hybrid will include 13 members. In order to compare the viability and economic effect of the different ways of organizing an evaluation structure, the four populations were examined in isolation.

In the case of single agents, the entity $\alpha = f(z_t - \overline{y})$ was estimated and the agents decided to hold on to their current innovation or to shift to a new innovation. In the case of evaluation structures including two or more agents, the evaluation structure was represented as a two-dimensional matrix with ones representing agents and zeros representing an absence of members. We then designed a procedure to extract the exact analytical expression for the evaluation structure's graph screening function $F_G(\alpha)$, i.e., the reliability polynomial.[3] The decision whether to explore a new innovation or further exploit the old was based on the probability $F_G(\alpha) = F_G(f(z_t - \overline{y}))$.

Selection pressures are commonly thought to be important sources of improvement in a population of innovators. We defined a selection mechanism in the following way. In each time-step, the average economic return that a manager has achieved at this point in time is compared to the current average result of the entire population. The comparison is made after all managers of a population have chosen an innovation and received their pay-off. If the manager in question does not meet the level of the γ best members in the population, he is removed from the population and replaced by a new manager. We examined selection pressure of $\gamma = \{0.50, 0.90\}$. Because the results are qualitatively similar, we only report the results from $\gamma = 50$. In the populations of hierarchies, polyarchies and hybrids, the effect of the selection pressure was to drive the less able structures out of the population.

For each of the four populations, the parameter space to be explored included a total of 36 combinations, i.e., six levels of managerial ability, three levels of the random component in value (σ), and two levels of selection pressure (γ). Reliable estimates were obtained by averaging over 100 samples for each population and for each combination of the parameters.

In order to compare the effect of evaluation structures with the commonly known version of the bandit problem (Sutton & Barto, 2000), we conducted a series of simulations without any selection effect. In order to do this, we used performance as a criterion to select one representative hybrid, hierarchy and polyarchy. We chose the best hybrid in the sense that it achieved the highest performance for the least average death rate.[2] We also used this procedure to chose a size of the hierarchy and of the polyarchy. In both cases, a structure of seven members was chosen.

[3]Christensen & Knudsen (2002) provides a pseudocode that can be used to develop a procedure to accomplish this.

[2] The screening polynomial of the best hybrid was:
$-3\alpha^{14} + 31\alpha^{13} - 150\alpha^{12} + 446\alpha^{11} - 896\alpha^{10} + 1253\alpha^{9} - 1205\alpha^{8} + 754\alpha^{7} - 274\alpha^{6} + 56\alpha^{5} - 24\alpha^{4}$
$+12\alpha^{3} + \alpha^{2}$.

4.2 Results

There are three main results. First, the level and bias of managerial ability significantly influences managerial performance. Second, evaluation structures influence managerial performance in a way that is contingent upon the nature of the environment within which the manager works. Evaluation structures must be designed to match the nature of the environment with respect to the competitive pressure, the variance in outcomes and the ability of the available employees. A third result is that selection effects help a population of managers with no ability to increase performance. All results are reported in Tables 1-3 in the Appendix.

As shown in Table 1, more ability is generally better in the sense of increasing the economic performance for less deaths. Sometimes, however, less managerial ability in evaluating the difference between innovations is a blessing. This is the case when there is no selection and when screening is biased. When selection effects are absent, the population cannot benefit from the exit of unsuccessful managers. In this case, perfect screening has a detrimental effect. Table 3 shows that the decline in economic performance from an increase in the level of screening, from A5 to A6 (perfect screening), is greatest when there is no uncertainty ($\sigma = 0$). Perfect screening is second best because perfection decreases the level of managerial exploration in the absence of selection effects; the manager prematurely decides to exploit a particular innovation. As the uncertainty in outcomes increases, the selection effect effectively leads to more exploration, and the loss from increasing ability diminishes.

More generally, the results of Tables 1 and 3 show that three factors jointly determine whether the level of exploration is too high or too low: the presence of selection effects, the level of managerial ability, and the level of uncertainty in outcomes. In the absence of selection, less than perfect ability leads to increased performance as uncertainty goes to zero. In the presence of selection, perfect ability leads to increased performance as uncertainty goes to zero. From a prescriptive viewpoint, it is therefore important to emphasize the contingent nature of the effects. The manager must choose the level of ability and the evaluation structure contingent upon the intensity of competition and the uncertainty in the value of innovations.

A bias is defined with respect to the reservation value, ξ. In the present study, we have set the reservation value to zero. We examined two forms of bias, a positive and a negative. A positive bias of 3 moves the agent screening function to the right such that the reservation value effectively becomes, $\xi' = 3$. By contrast, a negative bias of -3 moves the moves the agent screening function to the left such that the reservation value becomes, $\xi' = -3$. For example, as shown in Figure 1, Christie has a negative bias of -1. Simulations for two levels of positive bias (3, 10) and two levels of negative bias (-3, -10) are reported in Table 2 in the Appendix.

More ability in judging the difference between the current innovation and a new one is a curse when there is a strong negative bias (see Table 2). In this case, lower ability translates into the acceptance of more valuable innovations with a positive probability. By contrast, a positive bias increases the economic performance of the population. With a bias of 3, managers with ability A5, organized in a hybrid, achieved a cumulative economic performance of 3518, an impressive average per agent of more than 3.5 per time-step over the entire run. In comparison, the unbiased managers with perfect screening ability achieved a cumulative economic performance of 2050 ($\sigma = 0$). The issue here is that the manager benefits from a fairly high reservation value, $\xi' = 3$. This points to the identification of the optimal reservation value as a critical issue in the case where managers have less than perfect judgmental ability.

Having shown that managerial ability matters for performance, we now consider the role of evaluation structures. First, consider the dominance of hierarchies when the manager is a mere coin-flipper of no ability. Such a manager will accept a new alternative with probability 1/2 without consideration of its value. If the manager has already picked an innovation with positive value, the probability of accepting a worse innovation is higher than 1/2. This is so because there are 11 different arms in the model, one arm has zero value and 10 arms have symmetrically distributed positive and negative values ($\pm 1, \pm 2, ..., \pm 5$). Whenever the manager has chosen an arm with positive value, the probability that a random innovation has a higher value than the current innovation is less than the probability that it has lower value. By contrast, a manager with perfect ability to screen differences who happened to accept an innovation with positive value will only shift to a different innovation if it appears to have higher value. As the ability increases, the manager will quickly settle on an innovation with a relatively high value. A manager with less ability will continue exploring.

The hierarchy reduces the probability of accepting any proposal in the case of no ability. Starting from an innovation with positive value, the best strategy of the agent with no ability is simply to reject every alternative. For this reason, the hierarchy reduces the probability of choosing an innovation with lower value. The superior evaluation structure for managers with no ability is the hierarchy, promoting a strategy of choosing an innovation at random and then sticking to this innovation forever. The hierarchy is an evaluation structure that helps achieve this because it makes acceptance of a new innovation less likely. It is a skeptic structure that helps maintain the status quo, and maintaining the status quo is the best option if you have no ability in evaluating outcomes.

Obviously, rules or norms disfavoring change could be substituted for the hierarchy. In early stages of innovation when there is high uncertainty regarding the relative value of possible approaches to innovation, the classical managerial traits are boldness and determination to carry out an innovation despite the risks (Schumpeter, 1934). As Schumpeter (1934) argued, determination is crucial, ability of less importance. Our results are consistent with Schumpeter's (1934) arguments, but add new insights. In the face of no ability to judge the value of innovations, the more determined the manager, in the sense of sticking to one particular innovation, the better. When the ability to judge the value of innovations is increased above level A1, we find that the hierarchy is not necessarily the best way of organizing an evaluation structure. In the face of selection effects, the results in Table 1 show that the hierarchy is generally the best evaluation structure, closely followed by the hybrid. This result is influenced by the selection effect, giving rise to fierce competition among the many alternative hybrids.

When the selection pressure is removed (Table 3), we see that the hybrid is the superior evaluation structure for low levels of ability (A2 and A3) and low levels of uncertainty ($\sigma = 0.00, 0.30$). For higher levels of ability and a high level of uncertainty, the hierarchy again wins out. The reason is that the hierarchy decreases managerial exploration by rejecting alternatives that are only slightly better than the present. If ability is further increased to level A4 and A5, the evaluation structure has no distinct effect unless the manager's ability is biased. Indeed, the importance of evaluation structures decreases as the managerial ability increases. When the screening is positively biased, however, the hybrid remains the superior evaluation structure even for high levels of ability (A4 and A5 in Table 2).

Finally, the effect of selection is worth noting. When managers have no ability, they will achieve a result of zero unless there is selection. In the case of selection, the population of managers benefits from the exit of unsuccessful managers. When managerial ability is absent, selection effects are beneficial. As managerial ability increases, the gain from the exit of unsuccessful managers is lower than the loss of value.

5 Implications for Research

The resource-based view (RBV) of strategy has mainly focussed on sustaining the competitive advantage in firms endowed with resources that have superior value. Indeed, the RBV is silent on antecedents to the composition of the firm's resource portfolio, even though in the earliest formulations of the theory (Penrose, 1959), managerial decision making on the composition of the firm's resource bundle is a central component of the theory. Thus, a fundamental problem of explaining how differential resource value is attained in the first place remains unsolved in the RBV. The present article contributes by identifying this gap in the RBV and advances a perspective on evaluation of resource value that can help fill it. This perspective complements Makadok's (2001, 2003) analysis of the joint effect of agency problems and uncertain expectations of resource value influencing investment in resources. The present paper focusses squarely on the evaluation of resource value in the absence of agency problems (a transformation of ability, $\mathcal{T}(f_i)$ would allow representation of agency problems in the present framework).

The evaluation perspective, outlined in the present article, traces heterogeneity in resource value to differences in judgmental ability, both at the individual and the organizational level. While differential judgmental ability at the individual level gives rise to asymmetric information, evaluation structures give rise to complementarities among individuals. Asymmetric information arises if managers have differential ability in evaluating resource value (i.e., the screening functions of managers i and j differ, $f_i \neq f_j$). When such asymmetric information about resource value is absent ($f_i \equiv f_j$), individual managers will evaluate resource value in the same way (even though point estimates may differ, the expectations will be identical). Individual managers with identical judgmental ability will therefore deploy resources in a similar way. However, even managers with identical ability can achieve competitive advantage if they are located in different evaluation structures. The reason is that evaluation structures define information flows among organization members. These information flows introduce complementarities that are sources of differential outcomes (as illustrated in our simulation model). Such complementarities are formally expressed by the organizational level graph screening function F_G. The evaluation perspective developed in the present article thus aligns with Lippman & Rumelt's (2003b) conclusion that asymmetric information and complementarities are sources of superior resource value and thus competitive advantage. The present article also advances Lippman & Rumelt's (2003b) analysis by pointing to ability in evaluation and the organization of evaluation as important sources of asymmetric information and complementarities. The conclusions offered here extends to the problem of evaluating resources that are acquired in factor markets. Differential ability and differential ways of organizing evaluation are important sources of differential economic rents from resources that are picked in factor markets. The problem of evaluating resource value underlies both resource-picking and capability-building, as recently considered by Makadok (2001).

The implications for research in the RBV are fairly straightforward. We need empirical research that includes measures of judgmental ability and examines the relation between evaluation structures (or voting rules) that are actually used in business and the quality of the decisions that get made as regards resource acquisition, resource divestiture, and resource deployment. A related implication can be drawn for the empirical literature on entrepreneurial behavior, and in particular the recent studies of corporate entrepreneurship (Barringer & Bluedorn, 1999; Stevenson & Jarillo, 1990; Zahra, 1996). Researchers of entrepreneurial behavior may find that both judgmental ability and evaluation structures are important determinants of success in entrepreneurial ventures.

The analytical framework advanced here also has relevance for a broader set of literatures. In economics, the standard model of search (Rothschild, 1974; Stigler, 1962) assumes that agents are capable of perfect evaluation of the value of alternatives. Because the standard model of search is used to determine demand functions (Rothschild, 1974), the issue of imperfect evaluation should be of considerable interest, also for this topic.

The literature on organizational design has explored the issue of limited managerial ability in various ways (Gavetti & Levinthal, 2000; Levinthal, 1997; Rivkin & Siggelkow, 2003), but a systematic approach to the conceptualization and modelling of managerial ability in evaluating resources has not yet been developed. The present work provides an overarching framework that can be used to think about these issues in a systematic way. Limited managerial (or entrepreneurial) ability has usually been thought of as an issue of sample size. This is but one aspect of the actual limitations, another, and so far ignored limitation, is a limited ability to determine the value of a resource, or a particular use of a resource.

Considering limitations in managerial ability leads to additional insights regarding the nature and function of organizational structures. We found that the role of organizations in supporting fallible managers leads to design implications that complement the conventional view (Miles & Snow, 1978; Mintzberg, 1979). Hierarchies are not only useful because they promote control, efficient coordination and remedy transaction hazards, we also found that they are sources of superior performance in uncertain environments. This issue has been intensely debated in the literature (Miles & Snow, 1978; Mintzberg, 1979; Rivkin & Siggelkow, 2003), however the basis for our conclusion is new, i.e., limitations in the ability to evaluate alternatives. Whereas the extreme centralized structure, the hierarchy, was superior in a number of situations, we found that the opposite decentralized structure, the polyarchy, did not provide an advantage under any of the contingencies we examined. This raises some questions regarding the limits of decentralization. By contrast, hybrids had their superior moments because they could effectively increase the level of organizational ability beyond that of the individual manager. That is, we found that hierarchies are not only means to compromise between flexibility and control, they have a different property in enhancing managerial ability.

6 Conclusion

The issue of evaluating, discovering, and creating the value of resources is an unsolved problem at the center of the subject of business strategy. In order to understand how managers search for uses of higher value, we must understand the limits that constrain their ability. It has been recognized that limited rationality constrains the sample size of the alternative uses that a manager can examine (Gavetti & Levinthal, 2000; Levinthal, 1997; Rivkin & Siggelkow, 2003). The related issue of limits constraining the manager's ability in recognizing resource value, once a sample of alternatives has been identified (or generated) has not been given much attention (a recent exception is Knudsen & Levinthal, 2005). Yet, as the many studies of entrepreneurship indicate, this issue is of critical importance in practice.

Drawing on reliability theory, the essence of managerial ability can be expressed as the probability of making two forms of error, rejecting uses of high value (errors of omission) and accepting uses of poor value (errors of commission). Using this specification, we provided a way to model different levels of managerial ability and showed how the effect of alternative evaluation structures can be modelled.

We used the n-armed bandit problem, the canonical model of the exploration-exploitation dilemma, to illustrate how managerial ability, along with selection effects and uncertainty in outcomes, determined the value of the resources that were assembled by a population of managers. The simulation also illustrated how evaluation structures can help managers select innovations of better economic value. Even if managers are homogenous in their ability to recognize the value of resources, the particular evaluation structure within which managers are located will enhance or decrease the joint outcome of evaluation. Thus, evaluation structures give rise to judgmental ability at the *organizational level*.

The present study is motivated by a fundamental unsolved problem in the RBV of explaining how differential resource value is attained in the first place. The present article contributes by identifying this gap and advancing a perspective on evaluation of resource value that can help fill it. The evaluation perspective, outlined in the present article, traces heterogeneity in resource value to two sources, asymmetric information and complementarities. In our analysis, asymmetric information arises from differential judgmental ability at the *individual level*. Complementarities, in contrast, arise from evaluation structures. The evaluation perspective developed in the present article thus aligns with Lippman & Rumelt's (2003b) conclusion that asymmetric information and complementarities are sources of superior resource value and thus competitive advantage.

The basis for our conclusion is entirely new and invites a fresh look on organizations. Understanding the role of organization structures in remedying managerial fallibility opens a new and fascinating subject of study that is relevant to the RBV and a broader set of literatures mentioned in the above section on research implications. Empirical research on this topic as well as a better understanding also of the role of evaluation structures in shaping managerial search (and sample processes) and creativity should be high on the agenda in strategy research.

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7 Appendix

	S	P	H	Hy	S	P	H	Hy
A1, σ=0.00	125	121	238	120	4.86	4.98	4.72	5.00
A2, σ=0.00	744	722	892	871	2.62	3.30	2.69	2.99
A3, σ=0.00	1302	1243	1415	1398	2.74	4.07	2.94	3.60
A4, σ=0.00	1935	1908	1896	1975	15.11	15.05	18.06	13.22
A5, σ=0.00	1717	1736	1732	1685	31.08	29.31	30.37	31.29
A6, σ=0.00	2050	–	–	–	2.76	–	–	–
A1, σ=0.30	124	121	227	120	4.81	4.91	4.70	4.99
A2, σ=0.30	746	721	901	871	2.64	3.40	2.71	2.98
A3, σ=0.30	1288	1238	1416	1395	2.71	4.07	2.79	3.46
A4, σ=0.30	2110	2044	2143	2113	6.63	8.06	7.04	6.36
A5, σ=0.30	2130	2133	2137	2125	9.23	8.83	9.09	8.78
A6, σ=0.30	2183	–	–	–	5.74	–	–	–
A1, σ=3.00	142	140	250	137	5.38	5.45	5.27	5.51
A2, σ=3.00	700	680	818	787	3.19	3.62	3.27	3.31
A3, σ=3.00	1082	1054	1171	1161	3.02	3.65	3.18	3.13
A4, σ=3.00	1553	1536	1571	1548	3.21	3.27	3.27	3.18
A5, σ=3.00	1591	1593	1590	1591	3.28	3.21	3.25	3.21
A6, σ=3.00	1592	–	–	–	2.46	–	–	–

Table 1: Selection pressure, $\gamma = 0.50$ and three levels of uncertainty, σ. Cumulative performance at T=1000 and mean death rates, for each level of ability (A1= coin-flipper to A6= perfect screening) and each population of structures (S= Single agent, H= Hierarchy, P= Polyarchy, Hy= Hybrid). Each cell contains averages of 100 samples.

	S	P	H	Hy	S	P	H	Hy
A1, σ=0, Bias=3	124	121	223	119	4.84	4.97	4.75	5.03
A2, σ=0, Bias=3	944	921	1087	1177	2.65	3.31	2.75	3.46
A3, σ=0, Bias=3	1819	1770	1922	1902	3.87	5.09	3.98	11.62
A4, σ=0, Bias=3	3429	3325	3344	3474	13.76	13.98	13.62	12.24
A5, σ=0, Bias=3	3484	3394	3481	3518	16.59	18.46	16.45	15.30
A6, σ=0, Bias=3	3496	–	–	–	10.33	–	–	–
A1, σ=0, Bias=10	123	121	220	119	4.85	4.95	4.76	5.00
A2, σ=0, Bias=10	1296	1292	1454	1758	2.76	2.88	2.90	4.62
A3, σ=0, Bias=10	2071	2127	2138	2194	24.01	22.01	24.95	30.09
A4, σ=0, Bias=10	2712	2712	2679	2719	40.16	40.07	40.88	39.93
A5, σ=0, Bias=10	2703	2703	2680	2723	40.10	40.14	40.92	39.81
A6, σ=0, Bias=10	2686	–	–	–	40.67	–	–	–
A1, σ=0, Bias=-3	123	122	221	117	4.87	4.98	4.78	5.00
A2, σ=0, Bias=-3	547	526	681	582	2.97	3.67	3.00	3.07
A3, σ=0, Bias=-3	739	714	866	758	2.68	3.73	2.74	2.79
A4, σ=0, Bias=-3	947	917	978	944	2.68	3.39	2.78	2.70
A5, σ=0, Bias=-3	996	967	989	966	2.69	2.92	2.86	2.82
A6, σ=0, Bias=-3	789	–	–	–	2.13	–	–	–
A1, σ=0, Bias=-10	125	123	228	119	4.81	4.98	4.72	5.03
A2, σ=0, Bias=-10	223	216	308	189	3.89	4.13	3.91	4.46
A3, σ=0, Bias=-10	126	122	161	107	4.94	5.06	4.90	5.46
A4, σ=0, Bias=-10	69	70	71	70	6.49	6.46	6.46	6.47
A5, σ=0, Bias=-10	70	70	71	70	6.47	6.52	6.45	6.50
A6, σ=0, Bias=-10	71	–	–	–	6.48	–	–	–

Table 2: Biased screening and no uncertainty, $\sigma = 0$. A positive bias of, for example, 3 moves the point $(x = 0, f(x) = 1/2)$ to $(x = 3, f(x) = 1/2)$. Simulations for two levels of positive bias (3, 10) and two levels of negative bias (-3, -10) are reported. Selection pressure, $\gamma = 0.50$. Cumulative performance at T=1000 and mean death rates, for each level of ability (A1= coin-flipper to A6= perfect screening) and each population of structures (S= Single agent, H= Hierarchy, P= Polyarchy, Hy= Hybrid). Each cell contains averages of 100 samples.

	S	P	H	Hy
A1, σ=0.00	1	3	6	-1
A2, σ=0.00	953	887	1132	1146
A3, σ=0.00	1649	1562	1810	1858
A4, σ=0.00	2673	2636	2720	2655
A5, σ=0.00	2760	2745	2780	2733
A6, σ=0.00	2495	–	–	–
A1, σ=0.30	-2	-4	-5	-2
A2, σ=0.30	949	890	1130	1142
A3, σ=0.30	1647	1555	1806	1851
A4, σ=0.30	2666	2627	2711	2650
A5, σ=0.30	2738	2730	2742	2729
A6, σ=0.30	2722	–	–	–
A1, σ=3.00	2	4	2	-1
A2, σ=3.00	886	834	1034	1027
A3, σ=3.00	1390	1327	1507	1493
A4, σ=3.00	1980	1949	2009	1966
A5, σ=3.00	2025	2023	2025	2019
A6, σ=3.00	2008	–	–	–

Table 3: Standard run with no deaths, i.e., selection pressure, $\gamma = 0$ and three levels of uncertainty, σ. Cumulative performance at T=1000 and mean death rates, for each level of ability (A1= coin-flipper to A6= perfect screening) and each population of structures (S= Single agent, H= Hierarchy, P= Polyarchy, Hy= Hybrid). Each cell contains averages of 100 samples.