Organization Design

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This paper attempts to explain organization structure based on optimal coordination of interactions among activities. The main idea is that each manager is capable of detecting and coordinating interactions only within his limited area of expertise. Only the CEO can coordinate companywide interactions. The optimal design of the organization trades off the costs and benefits of various configurations of managers. Our results consist of classifying the characteristics of activities and managerial costs that lead to the matrix organization, the functional hierarchy, the divisional hierarchy, or a flat hierarchy. We also investigate the effect of changing the costs of various managers on the nature of the optimal organization, including the extent of centralization.
(*Organization Design; Hierarchies; Decentralization; U-Form; M-Form; Internal Organization*)

Organizations are observed to exist with various structures. Many organizations are designed as hierarchies, with each manager reporting to one and only one manager at the next higher level. Within the hierarchical structure, there is considerable variation in the number of levels and in the set of activities grouped together. The two main groupings are "divisional" and "functional." Other organizations employ a matrix structure in which each low-level manager reports to two or more superiors.

In a divisional hierarchy (sometimes called a "multidivisional" or "M-form" organization), all the activities pertaining to a single product, set of products, or type of customer (e.g., those in a given country) are grouped together into a division. For example, the operating segment of General Motors in the 1920s was organized into divisions corresponding to the various cars and trucks (Chevrolet, Sheridan, Oakland, Olds, Buick, Cadillac, GM Truck) plus the Accessory Division, the Samson Tractor Division, etc. (Sloan 1963, p. 57).

In a functional hierarchy (sometimes called the "unitary form" or "U-form"), by contrast, activities pertaining to a particular function are organized into departments. For example, by 1963 the operations area of General Motors was organized as a functional hierarchy whose departments were distribution, styling, engineering, manufacturing, research, public relations, and personnel (Sloan 1963, p. 190). In a functional hierarchy, the personnel department would, for example, coordinate personnel activities for all products.

Matrix structure, which involves "dual-authority relations" (Jennergren 1981, p. 43), can combine divisional and functional structures. For example, the president of a unit producing power transformers in Norway for Asea Brown Boveri (ABB) reports to the president of ABB Norway and to the head of the Power Transformer Business Area (Baron and Besanko 1997, p. 2).

To clarify the various ways firms are typically organized, consider the following hypothetical example. ABC Company produces and sells two versions of a product in two countries, Norway and the United States. Each version of the product requires occasional country-specific design adaptations, and, of course, each version must be marketed in each country. There are thus four basic tasks, design and marketing for each version of the product. These four activities may be organized into one of four commonly observed structures, depicted in Figures 1–4. In Figure 1, the structure is flat with the manager in charge of each

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Figure 1 Flat Structure

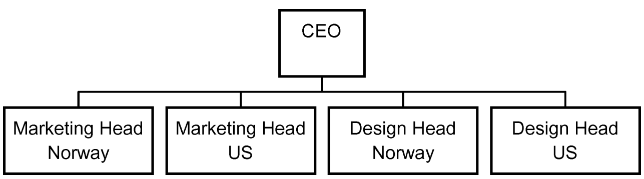


Figure 2 Divisional Hierarchy

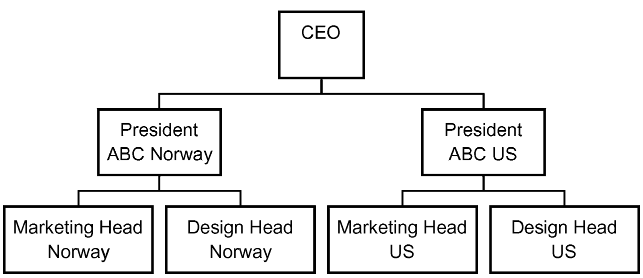


Figure 3 Functional Hierarchy

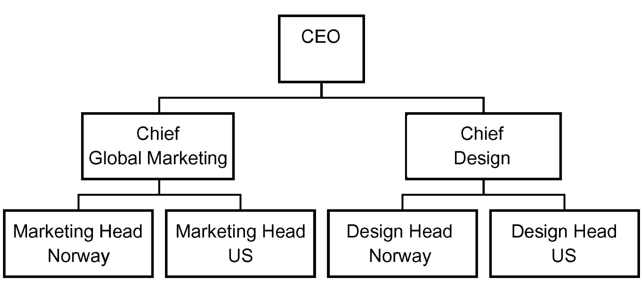
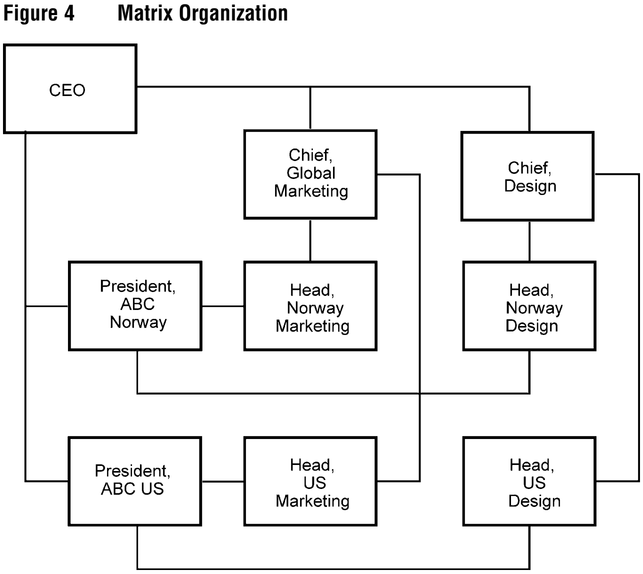


Figure 4 Matrix Organization



activity reporting directly to the CEO; an example is Nucor (Ghemawat 1995). Figure 2 depicts a divisional hierarchy in which there are two midlevel managers, each coordinating the two functions for a given country (product). In Figure 3, the hierarchy is organized along functional lines; i.e., each of the two middle managers is in charge of a function for both countries (products). Finally, Figure 4 shows a matrix organization in which each bottom-level manager reports to two middle managers; e.g., the marketing manager for Norway reports both to the middle manager in charge of Norway and the middle manager in charge of global marketing.

An interesting topic in the theory of the firm, relatively underexplored in the economics literature, is what determines whether an organization adopts a matrix or hierarchical structure, how many levels are involved, and how activities are grouped. Several authors in the organization behavior literature have argued that the choice between divisional and functional structures is driven by the relative importance of coordination of functional activities within a product line and economies of scale from combining similar functions across product lines (see Jennergren 1981 for a survey). The advantage of a divisional structure is that it allows better coordination among the various functions, such as manufacturing, product design, personnel, and marketing, required to produce and sell a product. Segregating these functions by product divisions, however, results in the failure to exploit economies of scale available if, for example, marketing for all products is handled by a central marketing department. Trading off these advantages, it is argued, determines whether one adopts a divisional or a functional hierarchy.

We address the issues relating to organization design mentioned above using a model based on coordinating interactions across various activities. In our view, coordinating interactions requires costly expertise embodied in managers. The optimal organizational structure trades off the benefits of coordination against the cost of the necessary expertise. In this sense it is similar to the arguments of organization theorists summarized in the previous paragraph. We provide a formal model that endogenizes the choice of organization structure, allowing us to make empirical predictions regarding the use of matrix vs. hierarchical structures, the extent of decentralization, and the choice of functional vs. divisional grouping.

We model a firm as consisting of activities such as producing products or components, designing products, marketing products, etc. Each activity originates with a "project manager" who is assumed to be essential to generating the activity and to have no function other than generating and possibly managing his activity. If a set of activities interacts, there are benefits to coordinating these activities. Discovering an interaction and reaping the benefits requires intervention by a manager with the correct expertise (project managers have no such expertise). The territory between the project managers and the CEO may be populated by various "middle managers." Each middle manager is capable of detecting and coordinating a specific pair of interactions. For example, a manager in charge of companywide marketing may discover that there are gains to advertising products jointly rather than in separate ad campaigns, and have the ability to design such a joint promotion. In addition to the benefits of coordinating pairs of activities, if all the pairwise interactions are present, there are incremental benefits to coordinating activities on a companywide basis. Only the CEO is capable of this companywide coordination (the CEO can also detect and coordinate pairs of activities). It is important to note that we abstract entirely from incentive problems. That is, in our model, managers act in the best interest of shareholders and have no incentive to hide or distort information that they discover.[1] We return to this issue briefly in the concluding section.

Managers may have two kinds of costs, a salary that must be paid if the manager is available to coordinate activities for the firm, regardless of whether that manager is actually used, and an opportunity cost of the manager's time that is incurred only if the manager's expertise is actually used to coordinate activities. This opportunity cost of the manager's time reflects his value in other activities not modeled here. For example, the opportunity cost of a CEO might reflect her value in strategic planning.

The organization design problem is to choose a set of middle managers who are available for coordinating activities and a set of instructions for using these managers, the project managers, and the CEO, given the costs of having and using these managers and the expected coordination benefits. Our results consist of classifying the characteristics of activities and managerial costs that lead to various structures. When the salaries of middle managers are high, no middle managers are employed, and the resulting structure is a flat organization consisting only of the CEO and the project managers. When the middle managers' salaries are low, the resulting structure resembles a matrix form rich in middle managers. For intermediate salaries of the middle managers, a hierarchy with some middle managers is optimal. We also show for which circumstances the hierarchy should be designed to exploit high-probability interactions and for which circumstances the hierarchy should be designed to exploit low-probability interactions. Increases in the opportunity cost of the CEO may also result in employing more middle managers as well as reducing the involvement of the CEO in coordination activities, i.e., reducing the centralization of decision making. Also, increases in the synergy gains from coordinating companywide interactions increase centralization.

It is not surprising that increases in the salaries of middle managers lead to reductions in their employment or that increases in synergy gains or reductions in CEO opportunity cost lead to greater centralization. To understand the intuition for the other results, it is helpful first to realize that the middle managers have two functions in our model. One is to coordinate pairs of projects when they interact. The other is to generate information that allows more efficient use of the CEO, i.e., to protect the CEO. In particular, middle managers allow a more accurate assessment of whether a companywide interaction is present. This information enables the firm to reap the benefits of companywide coordination in some situations in which it would otherwise be suboptimal. It also allows the

[1] While incentive problems may also be important determinants of organization structure (see Maskin et al. 2000, Qian 1994, Singh 1985, and the survey by Laffont and Mortimort 1997), we limit the scope of the current paper to a consideration of coordination issues.

firm to avoid wasting the CEO's time when the companywide interaction is unlikely to be present. Consequently, as the cost of the CEO's time in coordination activities increases, middle managers become more valuable in their function as protectors of the CEO. This dual role of middle managers also explains the counterintuitive result that sometimes it is optimal to adopt a hierarchy designed to discover and coordinate *low*-probability interactions. In particular, if the low-probability interactions are discovered, it is more likely that the companywide interaction is present, and, conversely, if the low-probability interactions are absent, there is no companywide interaction. Thus, using a hierarchy designed to discover the low-probability interactions allows more efficient use of the CEO's time than a hierarchy oriented toward discovering high-probability interactions. This will be especially valuable when the opportunity cost of the CEO is high.

A number of empirical implications follow from these results. Under certain additional assumptions, we show that organization structure will exhibit a sort of "life cycle" as the organization grows in complexity and size. In particular, we show that the structure will progress from a flat but highly centralized structure to a divisional hierarchy, to a functional hierarchy, and then either to a matrix structure or to a flat, highly decentralized structure. We also show that conglomerates that are organized as hierarchies may be expected to exhibit divisional, as opposed to functional, hierarchies. Finally, we show that firms that do not face tight resource constraints, highly regulated firms, and firms in stable environments will tend to have decentralized organizational structures.

The remainder of the paper is organized as follows. A brief review of the literature is contained in the next section. The model is presented formally in §2. We then solve the organization design problem in §3. Comparative statics results are presented in §4, empirical implications are considered in §5, and conclusions are presented in §6.

1. Literature Review

The economics literature on organization design is, as mentioned above, somewhat sparse. One approach, adopted by Radner (1993), is to assume that processing information takes valuable time. To reduce the delay, one can use "parallel processing" involving several people each processing part of the information at the same time. Delay reduction can be traded off against the cost of more "processors." Generally, this does not result in the types of organization structures we usually observe. Bolton and Dewatripont (1994) have a similar approach but emphasize the trade-off between specialization and communication. They show that in most cases the optimal organization structure combines a hierarchy with a "conveyer belt" type of structure. Sah and Stiglitz (1986) also focus on sequential vs. parallel processing of information but investigate the trade-off between Type I and Type II errors to determine when sequential processing is better than parallel processing and vice versa.

Garicano (2000) provides an elegant theory of hierarchies, based on expertise, that is similar in some respects to ours. He postulates the presence of experts who can be ranked according to the difficulty of the problems they can solve. Experts in a given cohort can solve all problems that can be solved by those in lower cohorts plus some more difficult problems. Experts who can solve more problems are correspondingly more expensive. More difficult problems occur less frequently than less difficult ones, however. This results in a pyramidical hierarchy with more workers at lower levels and fewer at higher levels. In analyzing hierarchies, we more or less assume a pyramidical structure but allow contingent referral of projects. We also consider experts with non-nested expertise allowing for the optimality of matrix forms.

Hart and Moore (1999) provide a model of hierarchies based on authority over the implementation of ideas for using assets. In their model, if individual i has authority over individual j with respect to ideas for a set of assets, then j's idea for those assets will be implemented if and only if i has no idea. The issue is how best to assign identical individuals to sets of assets, i.e., to which assets to assign each individual and in which order (where order indicates authority). Hart and Moore show that, under certain conditions, the optimal structure will involve a pyramidical hierarchy with individuals whose tasks cover a larger set of assets appearing higher in the chain of command. Although this model shares with ours the idea that coordination of activities is an important determinant of organization design, the approaches are quite different. The Hart–Moore model focuses on authority, whereas we focus on information. Their results explain authority relations but do not explain hierarchical groupings or matrix forms as we do. Hart and Moore relate the extent of centralization to the size of coordination benefits, whereas we focus on costs of expertise as the main determinants of centralization.

Vayanos (2002) stresses the interaction of information; i.e., the idea that the best project in a subset may depend on the nature of projects outside that subset. This feature is absent from other models in the economics literature, e.g., Radner (1993), Bolton and Dewatripont (1994), and Garicano (2000), but is one we emphasize. The application Vayanos (2002) models is portfolio selection. He assumes a hierarchy in which managers at each level examine a set of portfolios suggested by subordinates, and an exogenously determined set of assets. The main result is that each agent in the hierarchy has exactly one subordinate and also examines some assets directly.

Maskin et al. (2000) compare the M-form (divisional) and the U-form (functional) hierarchies. The main focus of the paper is to elaborate on the advantages of the M-form in providing incentives for division managers based on "yardstick competition." Although like the current paper Maskin et al. compares M-form with U-form, it does not consider the matrix form, and the basis for comparison of the two hierarchies is quite different. This leads to very different predictions about when one form is likely to dominate the other.

Stein (2000) compares decentralization with hierarchical structure. The advantage of a decentralized scheme in which division managers are allocated a fixed amount of capital is that these managers then have an incentive to produce information. On the other hand, under a centralized scheme, headquarters may reallocate capital away from a division, reducing incentives to produce such information. The advantage of the centralized system is that it enables headquarters to allocate capital more efficiently across divisions. This paper is more about centralization vs. decentralization than it is about the types of organizational forms we consider.

Another strand of literature emphasizes the role of rent seeking by managers with private information. McAfee and McMillan (1995) and Baron and Besanko (1992) consider the trade-off between the value of finer information, either from more levels or from more divisions, and the size of the additional informational rent that results.

The organization behavior literature has investigated the empirical relationships between decentralization of decisions and such variables as size (measured by employment) and vertical integration. Blau and Schoenherr (1971), Child (1973), Donaldson and Warner (1974), Hinings and Lee (1971), Khandwalla (1974), and Pugh et al. (1968) all find a positive relationship between size and extent of decentralization. Khandwalla (1974) also documents a positive relationship between vertical integration and decentralization. Child (1973) finds that the vertical span (number of levels) of hierarchy is positively related to size.

2. Model

We model a firm that, for tractability, is assumed to engage in only four projects, labeled A, B, C, and D, over a single period. Various subsets of these four projects may or may not interact. We denote an interaction between two projects by juxtaposing their labels; e.g., AB denotes an interaction between Projects A and B. The set of feasible pairwise interactions is denoted by $\Omega = \{AB, CD, AC, BD\}$. Note that we have excluded two interactions, AD and BC. This greatly simplifies the analysis and reflects the idea that some interactions are a priori extremely unlikely. For example, the design of a product intended for sale in Norway and marketing of the U.S. version of the product are not likely to interact directly. We refer to the event that all four possible interactions occurred as the "companywide" interaction.

To simplify the analysis and to capture the notion that some interactions tend to be similar to each other, we divide the set of feasible interactions, Ω, into two groups, $P = \{AB, CD\}$ and $R = \{AC, BD\}$. For example, suppose A is production of Tide, B is marketing of Tide, C is production of Cheer, and D is marketing of Cheer. Then the above grouping reflects the assumption that interactions within a product line (AB and CD) are similar to each other, as are interactions within functions (AC and BD). We take similarity to the extreme by assuming the interactions in a given group are identical in terms of probability of occurrence. Formally, assume that the probability of either interaction in P is p, and the probability of either interaction in R is r. We also assume that interactions are independent, and these probabilities are observed by everyone in the firm. We assume $p > r$; i.e., interactions between A and B and between C and D are the more likely interactions, while interactions between A and C and B and D are less likely. In terms of the above example, the assumption is that interactions within a product line are more likely than those across product lines. If, on the other hand, the economies of scale from combining production activities and those from combining marketing activities are more likely than interactions across functions within product lines, then we would simply relabel the activities.

There are three types of potential managers: project managers (one for each project), middle managers, and a CEO. Project managers are necessary to generate and manage the projects but cannot coordinate interactions between projects. They may, however, refer projects to middle management or the CEO for investigation and coordination of possible interactions.

If a set of projects does interact, there are benefits to coordinating them. Discovering and reaping these benefits requires investigation and coordination by a middle manager with the correct expertise (or by the CEO). For each interaction $\omega \in \Omega$, a middle manager, denoted m_ω, may be hired who can discover and coordinate this interaction and only this interaction. The set of potentially available middle managers is denoted by $M = \{m_\omega | \omega \in \Omega\}$. We can think of the middle managers in M as product division managers, managers of functional areas (e.g., marketing manager), country managers, etc., depending on the interpretation of the activities A, B, C, and D. Let M_P (M_R) denote the set of middle managers who can discover and coordinate interactions in P (respectively, R); i.e., $M_P = \{m_\omega | \omega \in P\}$ and $M_R = \{m_\omega | \omega \in R\}$. Incremental benefits from coordinating the pairwise interactions are assumed to be the same for all pairs and are normalized to one.[2] Thus, the probabilities p and r also play the role of expected benefits of the potential interactions.

The CEO is assumed to be able to discover and exploit any interaction, but only the CEO can exploit the companywide interaction which is assumed to be present if all four pairwise interactions occur. Incremental benefits from coordinating the companywide interaction are given by s.[3] The CEO generates benefits of 1 for each interaction present but not exploited by a middle manager, plus s if all four pairwise interactions are present.

This formalism admits many possible interpretations. For example, A and C can be electrical devices in Chevrolets and Cadillacs, respectively, and B and D can be bodies of Chevrolets and Cadillacs, respectively. If Project A is headlight improvement and B crash resistance, then A and B are likely to interact in that both improve the safety of Chevrolets. If they do interact, exploiting this interaction through a coordinated marketing effort emphasizing safety will produce incremental benefits. If, however, B is roominess, then A and B are unlikely to interact. One can interpret m_{AB} (m_{CD}) as the manager of the Chevrolet (Cadillac) Division and m_{AC} (m_{BD}) as the head of electronics (bodies).

As mentioned in the Introduction, managers have two costs, salaries and opportunity costs. The salary is a cost associated with employing the manager whether or not that manager is actually used to coordinate any projects. A manager's opportunity cost reflects his value in other activities within the firm that are not modeled here.

Because project managers are assumed to be essential to generating projects and to have no function other than generating and possibly managing projects, both costs of project managers can be

[2] It is easy to check that this benefit is a normalization in the sense that, as long as this parameter is constant, regardless of its level, it has no effect on the results. Later, we will consider briefly the effect of varying the incremental benefit of coordinating pairwise interactions.

[3] One role of the CEO in an organization may be to resolve conflicts in coordinating between two or more interactions involving the same project, e.g., between AB and AC. One can interpret s in our model as the benefit to such conflict resolution.

ignored. For simplicity, we assume that all middle managers have the same salary, denoted F, and that the middle managers have no function other than discovering and coordinating interactions between projects. Therefore, the opportunity cost of the middle managers is zero. The CEO, however, is assumed to have other duties such as strategic planning. Consequently, the CEO's opportunity cost, denoted by Q, is positive. These other duties of the CEO are sufficiently valuable that the CEO is required. As a result, her salary can be ignored. We further simplify the problem (and eliminate some uninteresting cases) by assuming that the value added by the CEO in coordinating the companywide interaction exceeds her opportunity cost, i.e.,:

Assumption 1. $s > Q$.

3. Optimal Organization Design

We find an optimal organization design in two stages. First, for each possible subset of available middle managers, we optimize their use and calculate the expected net benefits associated with this program. The overall organization design problem can then be solved by comparing these expected net benefits.

3.1. Optimal Use of a Given Set of Middle Managers

Given the available middle managers and the project characteristics, p and r, the problem is to decide which managers should be used to check for and coordinate possible interactions and in what order and in which contingencies they should be used. The problem is vastly simplified, however, by the assumption that the middle managers have no opportunity costs. It follows that it is optimal to use any middle managers that are available.

In the next three subsections, we analyze in turn the cases of no middle managers, two middle managers, and all four middle managers, respectively. We restrict the feasible subsets of middle managers to those that correspond to the commonly observed structures, i.e., flat, divisional or functional hierarchy, and matrix. Thus, we rule out structures involving three middle managers and those involving one middle manager from each group because these do not correspond to any hierarchy.

3.1.1. No Middle Managers: Centralized and Decentralized Flat Structure. When no middle managers are employed (i.e., the structure is flat), the problem is simply to decide whether to refer all four projects to the CEO or to give up any coordination benefits and let the project managers run the projects. We refer to the flat structure in which all projects are referred to the CEO as the *centralized flat structure*. The expected benefit of this structure is the expected benefit from coordinating the four pairwise interactions, $p+p+r+r$, plus the synergy gain, s, from the companywide interaction times the probability of the companywide interaction, p^2r^2. The cost of referring projects to the CEO is her opportunity cost, Q. Therefore, expected net profit for the centralized flat structure is $2(p+r)+p^2r^2s-Q$. We refer to the flat structure in which no projects are referred to the CEO as the *decentralized flat structure*. In this case, there are no coordination benefits and also no costs, so the expected net profit is zero. Therefore, the net value of the flat structure is

$$V_F = \max\{2(p+r)+p^2r^2s-Q, 0\}. \tag{1}$$

3.1.2. Two Middle Managers: Hierarchies. In this subsection we assume that only managers in M_R are available or only those in M_P are available. We derive, for each case, the optimal use of the given two managers.

First suppose only managers in M_R are present. This structure resembles a hierarchy in which each project is referred (at most) to one and only one manager at the next level: Projects A and C are referred to m_{AC} and Projects B and D are referred to m_{BD}. Consequently, we refer to this situation as the R-hierarchy.

To calculate the value of an optimal strategy in this case, we use backward induction. Suppose projects have been referred to the two managers in M_R. At this point one may either stop or refer all projects to the CEO. In the former case, the middle managers coordinate their interactions, and the CEO is not involved. Consequently, we refer to this case as the *decentralized R-hierarchy*. In the latter case, the middle managers coordinate their interactions, while the CEO coordinates the other pairwise interactions and the companywide interaction. Accordingly, we refer to this case as the *centralized R-hierarchy*. Stopping results in a net additional expected benefit of zero. If the two managers in M_R both found interactions (this happens with probability r^2), the additional expected benefit of referring all projects to the CEO consists of the expected coordination benefits for the two projects in P, $2p$, and the expected companywide synergy gain, p^2s. The cost of referring to the CEO is Q, so the expected net benefit is $2p+p^2s-Q$. If at least one of the interactions from the R group failed to occur (this happens with probability $1-r^2$), the additional net benefit of referring all projects to the CEO is only $2p-Q$, because the companywide interaction is not present in this case. Thus, the expected value of an optimal continuation strategy, given that both managers from M_R have been consulted, is $r^2 \max\{2p+p^2s-Q, 0\} + (1-r^2)\max\{2p-Q, 0\}$. The expected benefit from referring projects to the two middle managers is simply $2r$. Therefore, the optimal value of the R-hierarchy is

$$V_R = 2r + r^2 \max\{2p+p^2s-Q, 0\} + (1-r^2)\max\{2p-Q, 0\} - 2F. \tag{2}$$

When only managers in M_P are present, the design is referred to as the P-hierarchy. By symmetry we have the following analogous value for the P-hierarchy:[4]

$$V_P = 2p + p^2 \max\{2r+r^2s-Q, 0\} + (1-p^2)\max\{2r-Q, 0\} - 2F. \tag{3}$$

3.1.3. Four Middle Managers: Matrix Structure. As mentioned above, given that all four middle managers are present, it is optimal to have them investigate the four possible interactions first, before referring any decisions to the CEO. This strategy allows the firm to reap any benefits from interactions that are present and involve the CEO only if it is known that a companywide interaction requiring her special expertise exists. The strategy corresponds to the matrix organization described in the Introduction. That is, each project manager refers his project to two upper-level managers: Project A is referred both to m_{AB} and m_{AC}, Project B is referred both to m_{AB} and m_{BD}, etc.

Using Assumption 1, the value of the matrix organization net of salaries is

$$V_M = 2(p+r) + p^2r^2(s-Q) - 4F. \tag{4}$$

The intuition for this expression is as follows. Given that all four middle managers will be used and that if the companywide interaction occurs, projects are referred to the CEO, the expected benefit is the expected benefit from each single interaction, $p+p+r+r$, plus the expected value-added of the CEO net of her opportunity cost, $p^2r^2(s-Q)$. The expected cost is the salaries of the four middle managers, $4F$. The difference between the expected benefit and the expected cost gives the value of the matrix form in (4).

3.2. Overall Best Design

To calculate the optimal design, we make an additional assumption that is consistent with the spirit of Assumption 1, namely that the value-added of the CEO in coordinating activities is large. Specifically, we assume that $r^2(1-p^2)s > 2p$. The optimal design is given in Proposition 1. (All formal proofs are in an appendix available as an electronic companion on the *Management Science* website at ⟨mansci.pubs.informs.org⟩).

PROPOSITION 1. *Assuming $r^2(1-p^2)s > 2p$, the optimal organization design as a function of the opportunity cost of the CEO, Q, and the salaries of middle managers, F, is given by Table* 1.

Intuition for this result is given along with the discussion of the comparative statics results in the next section.

4. Comparative Statics

In this section we analyze how the optimal design varies with the opportunity cost of the CEO, Q; the salaries of the middle managers, F; the synergy gains

[4] Note that for the R-hierarchy, if $Q < 2p$, then all projects will eventually be referred to the CEO no matter what is discovered by the middle managers. A similar statement holds for the P-hierarchy when $Q < 2r$. For either hierarchy, this is equivalent to simply referring all projects directly to the CEO, skipping the middle managers. In this case, hierarchies would clearly be suboptimal, because a hierarchy would provide the same benefit as the centralized flat structure but would cost $2F$ more. Consequently, in an optimal design, if a centralized hierarchy is used, it will be one in which the CEO is involved only if both middle managers find interactions.

Table 1 Optimal Design As a Function of Q and F

For $Q \in$	Optimal design
$[0, 2r)$	Centralized flat if $4F > A(Q)$, matrix otherwise
$[2r, 2p)$	Centralized flat if $4F > \max\{A(Q), B_{pr}(Q)\}$, matrix if $4F < \min\{A(Q), C_{pr}(Q)\}$, centralized P-hierarchy otherwise
$[2p, G)$	Centralized flat if $4F > \max\{A(Q), B_{pr}(Q), B_{rp}(Q)\}$, matrix if $4F < \min\{A(Q), C_{pr}(Q), C_{rp}(Q)\}$, centralized P-hierarchy if $C_{pr}(Q) < 4F < B_{pr}(Q)$ and $Q < J$, centralized R-hierarchy otherwise
$[G, 2r + r^2 s)$	Decentralized flat if $4F > \max\{D(Q), K_{pr}(Q), K_{rp}(Q)\}$, matrix if $4F < \min\{D(Q), C_{pr}(O), C_{rp}(Q)\}$, centralized P-hierarchy if $C_{pr}(Q) < 4F < K_{pr}(Q)$ and $Q < J$, centralized R-hierarchy otherwise
$[2r + r^2 s, 2p + p^2 s)$	Decentralized flat if $4F > \max\{D(Q), 4p, K_{pr}(Q)\}$, matrix if $4F < \min\{D(Q), E(Q), C_{pr}(Q)\}$, decentralized P-hierarchy if $E(Q) < 4F < 4p$ and $Q > T$, centralized R-hierarchy otherwise
$[2p + p^2 s, \infty)$	Decentralized flat if $4F > \max\{D(Q), 4p\}$, matrix if $4F < \min\{D(Q), E(Q)\}$, decentralized P-hierarchy otherwise

$A(Q) = Q(1 - p^2 r^2) = D(Q) - G + Q$	$E(Q) = 2[2r + p^2 r^2 (s - Q)] = 2D(Q) - 4p$
$B_{xy}(Q) = 2(1 - x^2)(Q - 2y) = K_{xy}(Q) - 2(G - Q)$	$G = 2(p + r) + p^2 r^2 s$
$C_{xy}(Q) = 4y(1 - x^2) + 2x^2(1 - y^2)Q = 2D(Q) - K_{xy}(Q)$	$J = 2(1 + pr)/(p + r)$
$D(Q) = 2(p + r) + p^2 r^2 (s - Q)$	$T = 2p + p^2 s - 2(p - r)/r^2$
	$K_{xy}(Q) = 4x + 2x^2(2y + y^2 s - Q)$

of coordinating the companywide interaction, s; and the probabilities, p and r. To facilitate this analysis, we present the results in Table 1 in the form of a graph that shows, for each pair (Q, F), the optimal organization design.

Notice from Table 1 that the optimal design involves the relationship between $4F$ and the maximum or minimum among several linear functions of Q. Which of these linear functions is maximal or minimal turns out to depend on the relationships among several parameters that themselves depend on p, r, and s. In the online appendix, we show that there are six possible graphs. The six graphs are similar from the point of view of comparative statics results, the main differences being that for some configurations, one or more organization designs is suboptimal for all combinations of Q and F. In particular, of the six possible structures listed in Table 1, both flat structures, the matrix organization, and the decentralized P-hierarchy appear in all graphs. In some configurations, however, one or both of the centralized P- and R-hierarchies is suboptimal for all combinations of Q and F. In the text, we present and discuss in detail only one figure, Figure 5, in which all six designs appear; i.e., each of the six is optimal for some region of the Q-F parameter space.[5] The other cases are included in the appendix.

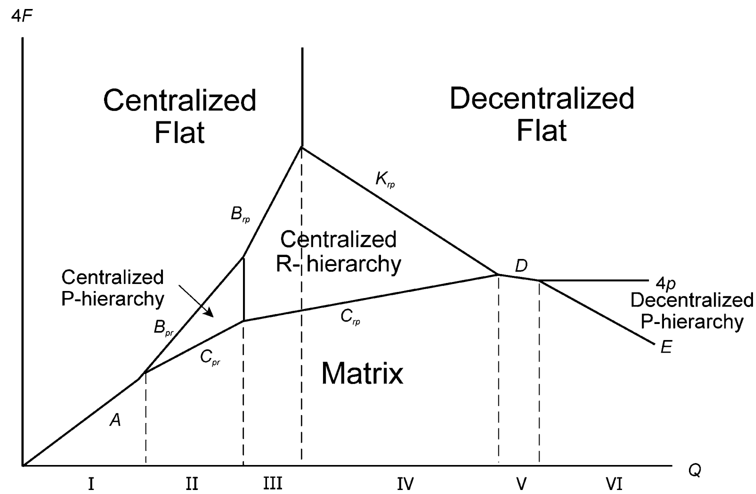
Generally speaking, Proposition 1 implies that when the middle managers' salaries are high, the flat structure is optimal. It is not surprising that when middle managers are expensive, it is optimal to do without them. One employs the flat structure with high CEO involvement (centralized) when the opportunity cost of the CEO's time is low, and the flat structure with low CEO involvement (decentralized) when her opportunity cost is high. When the middle managers' salaries are low, the matrix organization is optimal (except for very low CEO cost). If the middle managers are sufficiently inexpensive, it is optimal to hire all four (especially if the CEO is fairly expensive). This guarantees all pairwise interactions are exploited and that one never uses the CEO to coordinate projects unless the companywide interaction is present. For intermediate salaries of the middle managers, one of the hierarchies is optimal (which one depends on the opportunity cost of the CEO).

In what follows we discuss the effect of increasing the salaries of the middle managers on the optimal design for various values of the CEO's opportunity cost using Figure 5 (results are qualitatively similar for the other figures).

For Q in Region I of Figure 5, except for very low values of F, the firm will exhibit the centralized flat structure in which there are no middle managers and all projects are referred to the CEO. For very low F, however, one obtains the same result (i.e., all interactions are exploited) more inexpensively by hiring all four middle managers (i.e., the matrix organization)

[5] This graph corresponds to Case 3 in the online technical appendix available on the *Management Science* website at ⟨mansci.pubs.informs.org⟩.

Figure 5 Optimal Organization Design for a Typical Case



and incurring the cost of the CEO only when the companywide interaction is present. One might wonder why, as F increases, it is not optimal to move from the matrix organization to one of the hierarchies. The reason is that for such low values of Q it is never optimal to forego coordination benefits (as sometimes happens when using a hierarchy) to save on CEO costs.

For Q in Region II, as F increases, the optimal design changes from the matrix organization to the centralized P-hierarchy to the centralized flat structure. The intuition is similar to the previous situation, except that now Q is sufficiently large that it is optimal, for an intermediate range of salaries, to hire only two middle managers and forego some coordination benefits if at least one of the two middle managers fails to find an interaction. The advantage of the P-hierarchy is that, by starting with the high-probability interactions, one obtains a larger expected benefit from the two middle managers ($2p$ vs. $2r$) and has a higher probability of obtaining the benefits of the other interactions than if one had started with the low-probability interactions. The disadvantage of the P-hierarchy is that there is a greater chance of wasting the CEO's time because the low-probability interactions are less likely to be present. Because the CEO's opportunity cost is still relatively low, the advantages of the P-hierarchy over the R-hierarchy outweigh the disadvantage.[6]

For Q in Region III, the situation is similar to that of the previous paragraph, except that now, for intermediate values of F, the centralized R-hierarchy is optimal (instead of the centralized P-hierarchy). The intuition is the same as above, except that because the opportunity cost of the CEO is larger, the disadvantage of the P-hierarchy relative to the R-hierarchy outweighs its advantages.

For Q in Region IV, the situation is similar to that of the previous paragraph, except that now, for large values of F, the decentralized flat structure is optimal (instead of the centralized flat structure). The intuition is simply that the CEO's opportunity cost is sufficiently high that it is no longer worthwhile to refer all projects directly to the CEO when there are no middle managers.

For Q in Region V, as F increases the optimal design changes directly from the matrix organization to the decentralized flat structure. For this range of Q, the CEO is so expensive that, even if both low-probability interactions are known to be present, it is not worth taking a chance on incurring the cost Q to obtain the remaining coordination benefits. Thus, if a hierarchy

[6] This discussion makes it clear that the assumption that the companywide interaction occurs if and only if all four pairwise interactions occur is stronger than is necessary. What is essential is that the conditional probability of the companywide interaction, given that two of the pairwise interactions occurred, decreases in the probability of the two pairwise interactions.

were used, it would be used in its decentralized form. Clearly, the decentralized P-hierarchy dominates the decentralized R-hierarchy (both obtain the benefits of only two pairwise interactions, but the P-hierarchy obtains these benefits with higher probability). The P-hierarchy is better than the decentralized flat structure only if $p > F$. For F below p, however, the matrix organization is better than the P-hierarchy for Q in this range; i.e., the expected net benefit of the two additional pairwise interactions, $2r$, and the companywide interaction, $p^2r^2(s-Q)$, exceeds the cost of the two additional middle managers, $2F$, required to obtain them.

For Q in Region VI, the same argument as in the previous paragraph that the decentralized P-hierarchy is the best hierarchy applies. In this case, however, Q is sufficiently large and the expected net benefits of exploiting the companywide interaction, $p^2r^2(s-Q)$, sufficiently small, that there is a range of $F < p$ such that it is not worth paying the two additional managers. Thus, for Q in Region VI there is a range of F such that the optimal design is the decentralized P-hierarchy.

Note that as Q increases, holding F constant, the optimal design moves from the centralized flat structure in which projects are always referred to the CEO, toward either the decentralized flat structure or the decentralized P-hierarchy. In either of the latter two cases, projects are never referred to the CEO. For in-between values of Q, the optimal design may move from the centralized P-hierarchy to the centralized R-hierarchy to the matrix organization. The probability with which projects are referred to the CEO in these designs decreases from p^2 to r^2 to p^2r^2. Although one or more of these intermediate structures may be missing from the progression (see the appendix), in all cases the probability of CEO involvement decreases as the optimal design changes with increases in CEO opportunity cost.

A similar result holds if instead of increasing Q, we imagine decreasing the incremental benefit of the pairwise interactions. In particular, if all four pairwise interactions are assumed to have the same incremental benefit, and if the companywide synergy gain is proportional to the pairwise benefit, then decreases in this benefit are equivalent to proportionate increases in both Q and F. That is, decreases in the pairwise benefit are like moving away from the origin along a ray in Figure 5. Regardless of the starting point, such movement results in a progression similar to that of increasing Q, i.e., a progression of structures exhibiting decreasing centralization.

We summarize these results in the following proposition.

Proposition 2. *As Q increases or the benefits of the four pairwise interactions decrease, ceteris paribus, the probability that projects are referred to the CEO decreases.*

This completes our comparative statics on Q and F. Comparative statics results on p and r are difficult to prove in general, because all the boundaries of the various regions in Figure 5 (and the figures in the appendix as well) shift in complicated ways with p and r. One result we can obtain, however, concerns the special case in which r is very small. It is easy to see from Equations (1)–(4) that the R-hierarchy, the centralized P-hierarchy, and the matrix organization are strictly suboptimal when $r = 0$. By continuity, this statement also holds for $r > 0$, but sufficiently small (as long as $F > 0$). The result is quite intuitive: When the probability of low-probability interactions is sufficiently small, it makes no sense to pay the salaries of middle managers who are experts in detecting and coordinating these interactions or to waste the time of the CEO in such activities. We summarize this result in the following proposition.

Proposition 3. *For r sufficiently small, the R-hierarchy, the centralized P-hierarchy, and the matrix organization are strictly suboptimal.*

Finally, we consider comparative statics results for s.

Proposition 4. *Increases in the synergy gain from exploiting the companywide interaction, s, may cause the optimal design to change from a decentralized to a centralized structure, but not the reverse.*

5. Empirical Implications

First, consider the optimal organization design of conglomerates. For such highly diversified firms, it seems reasonable to suppose that the most likely interactions are those across functions within a given product, and interactions across products are extremely unlikely. In terms of our model, conglomerates are firms in which the interactions with probability p are those within products, and r is very small. Consequently, Proposition 3 predicts that highly diversified conglomerates will not exhibit the matrix form, and those organized as hierarchies will be organized as *divisional* hierarchies, i.e., along product lines, as opposed to functional hierarchies.

Second, consider the result of changes in the opportunity cost of the CEO's time in coordinating projects. As the size or complexity of the firm increases, the number of other activities to which the CEO may contribute (including other coordination activities) increases. Moreover, it is likely that the value of the CEO's time in activities other than coordinating the activities we model also increases with the size and complexity of the firm. Consequently, we take the size or complexity of the firm to be a proxy for the CEO's opportunity cost. The model thus makes a prediction regarding the "life cycle" of the firm's organization structure.[7] In particular, it suggests that young firms will have a centralized flat structure in which the CEO is highly involved in coordinating activities. Moreover, Proposition 2 implies that as the firm matures the frequency with which projects are referred to the CEO will decrease. This result is consistent with the findings of the organization behavior literature cited in §1, which documents a positive relationship between size and extent of decentralization.

In addition to the above prediction regarding the extent of centralization, the model also makes specific predictions for the evolution of a firm's organization structures over its life cycle. Young firms have organization structures that are flat with a high degree of CEO involvement in coordinating activities. As the firm matures, the firm's organizational structure will evolve in one of three basic directions:

- Directly to a highly decentralized structure with no middle managers and little involvement of the CEO. This evolution will characterize firms for which middle managers' salaries are high.
- To the matrix organization, then to a decentralized hierarchy that exploits the most likely interactions. This evolution will characterize firms with inexpensive middle managers.
- To a centralized hierarchy followed either by a decentralized flat structure or by a matrix that is then followed by a decentralized hierarchy. This centralized hierarchy may be designed to exploit either the more likely or the less likely interactions or may switch from the more likely to the less likely as the CEO's opportunity cost increases. This evolution will characterize firms for whom middle managers are neither expensive nor inexpensive.[8]

Further implications are available if we identify more specifically which interactions are most likely and which are least likely. Suppose interactions between functions relating to a given product are more likely than economies of scale from combining a function across products. In this case, if, as the size/complexity of the firm increases, the firm's organization structure changes from one type of centralized hierarchy to the other, the progression will be from a divisional (P-)hierarchy to a functional (R-)hierarchy. Moreover, if the firm exhibits a decentralized hierarchy, it will always be a decentralized divisional hierarchy.

Next we examine the effects of changes in the incremental benefit of coordinating companywide interactions, s. Recall from Proposition 4 that increases in s shrink the set of combinations of Q and F that result in decentralized structures. Possible empirical proxies for s include tightness of resource constraints, the extent to which incentive schemes focus on unit performance, the extent of regulation, and the stability of the environment. When units must compete for scarce corporate resources, the gains to companywide coordination of the allocation are likely to be large. Similarly, when compensation schemes do not give unit managers an incentive to take account of the effects of their choices on the company as a whole, there should be greater benefits to coordination by the CEO. On the other hand, severe regulation may allow little

[7] In discussing the life-cycle implications of the model, we are holding constant the salaries of middle managers as well as other parameters.

[8] These statements are true in all cases except one. In that case, the firm never exhibits a centralized hierarchy (see Case 1 in the online technical appendix).

scope for the CEO to improve performance through coordination of activities. Likewise, stable environments do not require frequent intervention by the CEO to reap coordination benefits. Thus, firms with weak resource constraints, compensation schemes that reward companywide performance, strong regulatory constraints, and/or stable environments are more likely to have highly decentralized organization structures.[9]

Finally, consider the impact of changes in the salaries of the middle managers holding the opportunity cost of the CEO, Q, fixed. From the discussion in §4, as salaries increase, perhaps because of increased demand for middle managers, one expects firms to move toward flatter structures. This might involve changing from a matrix form to a hierarchy or to a flat structure. For firms whose CEOs have relatively low opportunity cost of coordinating projects, as middle management salaries increase, the organization design will change from the matrix form to a centralized flat structure, possibly passing through a centralized hierarchical structure. For firms whose CEOs have relatively high opportunity cost of coordinating projects, as middle management salaries increase, the organization design will change from the matrix form to a decentralized flat structure, possibly passing through a hierarchical structure. Note, however, that in testing such implications it is important to control for changes in the other parameters. In particular, it is likely that when salaries increase, so do the benefits provided by middle managers, presenting a difficult identification problem.

6. Conclusions

This paper attempts to explain organization structure based on optimal coordination of interactions among activities. The main idea is that each middle manager is capable of detecting and coordinating interactions only within his limited area of expertise. Only the CEO can coordinate companywide interactions. The optimal design of the organization trades off the costs and benefits of various configurations of managers.

The model provides a number of empirical predictions regarding firms' organization design. In obtaining these results we made a number of simplifying assumptions. Perhaps the most important of these is that middle managers have no opportunity cost of coordinating interactions. This assumption allows us to ignore a large number of solutions that would be optimal for various levels of this opportunity cost. Because these solutions are rarely observed in practice, we believe that ignoring the opportunity cost of middle managers is justified.

A more important abstraction embedded in the model is the absence of incentive problems. These introduce a large set of considerations revolving around providing incentives to transfer information truthfully across managers within the organization structure. In particular, centralization of decisions will, no doubt, be more costly in such situations. This will bias the organization design toward flatter structures. Moreover, one of the costs of the matrix organization is that it may lead to conflicting incentives because some units report to multiple managers, while a divisional structure may lead to the production of information useful in providing incentives (see the model of Maskin et al. 2000 discussed above).[10]

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[9] Obviously, in testing these predictions, one must control for Q and F. For example, it is plausible that regulated firms have lower Q, which would be a force for more centralization in such firms. Also, of course, incentive schemes are endogenous, so one cannot infer causality. We mean simply to suggest that these two features of an organization design, i.e., compensation that rewards companywide performance and decentralization, might tend to occur together.

[10] A technical appendix to this paper is available as an electronic companion on the *Management Science* website at ⟨mansci.pubs.informs.org⟩.

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