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Attribute Coordination in Organizations

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We study coordination in organizations with a variety of organizational forms. Coordination in organization is modeled as the adjustment of attributes and capacities of tasks when facing external shocks. An M-form (U-form) organization groups complementary (substitutable) tasks together in one unit. In the presence of only attribute shocks, particularly when gains from specialization are small, communication is poor, or shocks are more likely, the expected payoff of the decentralized M-form is the highest. When facing both types of shocks, centralization does better if communication is good. The implications of organizational forms for the patterns of innovations and reforms within an organization, particularly centralized versus decentralized experiments and top-down versus bottom-up reforms, are discussed

Key Words: Organization forms; Coordination; M-form; U-form.
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1. INTRODUCTION

This paper studies coordination problems in organizations characterized by a variety of organizational forms. There are two main motivations for studying coordination and organizational forms. The first motivation is to understand the organizational structure of business firms. There are several strands along this line. First, in their studies of the evolution of organizational forms of corporations, Chandler (1962, 1977, 1990) and Williamson

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(1975, 1985) analyzed the emergence of the modern multi-divisional corporations (the M-form firm) in the 1920s, which became the prevailing organizational form of large businesses. An M-form firm is more efficient than a U-form firm because daily operations are decentralized to divisions, which frees the time of the central office for strategic planning. Second, the management science literature distinguishes product focused from process focused organizations, as well as product design innovation from process innovation. It is argued that alternative organizational forms are the result of minimization of coordination costs in unstable environments (Henderson and Clark, 1990, Hayes, Wheelwright, Clark, 1988, Stinchcombe, 1990, Athey and Schmutzler, 1995). Third, recent research in comparative institutional analysis emphasizes organizational features of firms across countries and over time. Aoki (1986) noted that in Japanese firms, decision making is more decentralized to workers who are less specialized and are more able to make frequent adjustments and use on-site information than their American counterparts. In their studies of the organization of modern manufacturing, Milgrom and Roberts (1990, 1992) underscored the advantage of the flexibility induced by the organizational structure in modern manufacturing and complementarity of underlying activities.

The second motivation of this study is to understand the organizational structure of centrally planned economies and its impact on the transition to markets. Qian and Xu (1993) distinguish two organizational forms of centrally planned economies. The organizational form of planning in Eastern Europe and the former Soviet Union was characterized by a unitary hierarchical organization based on functional and specialization principles ("U-form") (Nove, 1980, Gregory and Stuart, 1981, and Ericson, 1991). In contrast, the planning structure of China was mainly along regional lines which can be characterized as a multi-layer-multi-regional form of organization ("deep M-form"). Qian and Xu argue that this pre-existing organizational structure, together with further decentralization along regional lines during the reform, is the key to understanding China's transition to markets. In a different paper, Qian, Roland, and Xu (1999) argues that this structure provides a kind of flexibility and allows for regional experiments without interfering with the rest of the economy, makes a bottom-up approach or incremental reforms beneficial. This argument is consistent with some earlier observations (e.g., McMillan and Naughton, 1992).[1] Maskin, Qian, and Xu (2000) provide an analysis of incentive problems in M- form and U-form organizations. They analyse how different organizational forms give rise to different information about managers' performance, which will affect how incentives are designed in those organizations. They show that

[1]In contrast, we observe more frequently a top-down approach with radical programs in Eastern Europe and the former Soviet Union.

the M-form may provide better incentives than the U-form because it promotes relative performance evaluation more effectively. In this paper, we assume away incentive problems and all of our results are driven by coordination considerations.

Influenced by the above research, we will study in this paper some common issues concerning coordination (and its possible breakdown) in its relationship with alternative organizational forms. In our framework, we take "tasks" as the basic unit of analysis. We distinguish two kinds of coordination inside an organization. The first concerns attribute matching (or fit) among the tasks and the second relates to resource allocation for carrying out the tasks. While previous studies of coordination almost exclusively focused on resource allocation, we emphasize that attribute matching is an indispensable part of coordination and deserves attention. In particular, the attribute matching problem differs from the resource allocation problem because the latter almost always involves some substitutions of resources among tasks when an organization adjusts to exogenous shocks, but the former does not.

In our model, organizational forms consist of two dimensions: grouping of tasks into units and allocation of authority for coordination. An M-form organization is defined as one in which the tasks involving more attribute matching problems are grouped together in one unit. In contrast, a U-form organization is one in which similar tasks are grouped together into one unit. We think this definition is quite general to cover the range of phenomena discussed in different contexts. We consider centralization and decentralization (or delegation) of coordination as additional dimensions to the organizational design, which theoretically can be associated with either M or U forms.

Under the Hayekian assumption that only those people doing the tasks have the best local information about the environment, different organizational forms endogenously determine different information structures of the organization. This has major implications for the performance of an organization. We show that the decentralized M-form has an advantage in dealing with attribute shocks and the decentralized U-form has an advantage in dealing with capacity shocks, and centralization has an advantage over decentralization in the presence of both attribute shocks and capacity shocks if communication is good.

Organizational forms not only affect performance of the organization in routine activities, they also have profound impacts on innovation activities. An innovative idea involves a change of attributes or an introduction of a set of new attributes. However, newly designed attributes may not be compatible with the local conditions and some attributes have to be adjusted. Therefore, experimenting with a new idea endogenously introduces "shocks" to some attributes. Facing such an uncertainty, different organizational forms choose different patterns of innovation and experiments. In particular, we compare centralized experiments with decentralized experiments, and top-down with bottom-wp approaches of reforms.

The paper is organized as follows. Section 2 sets up the model. Section 3 introduces several examples from the literature of business organizations, military organizations and centrally planned economies. Section 4 analyzes coordination problems under attribute shocks, while Section 5 addresses coordination problems under capacity shocks. Section 6 combines the two types of shocks. Section 7 analysis experiments, innovation, and reform. Our conclusions follow.

2. THE MODEL

Following the team theory tradition, we will assume away the problem of incentives in order to focus on coordination (Marschak and Radner, 1972, Arrow, 1974). Several theoretical papers on coordination have had great influence on our work. We mention here especially Marschak and Radner's book (1972) on economic theory of teams, Weitzman's (1974) paper on coordination using price and quantity, Crmer's (1980) paper on the optimal partition of workshops inside an organization, Aoki's (1986) comparison of horizontal and vertical information structures and the extension to five informational structures (Aoki, 1995), and Milgrom and Roberts' (1992) notions of design attributes and innovation attributes.

While many previous researchers on organizations have assumed reduced forms of cost functions, we intend to open up the black box of decision-making inside an organization. Specifically, we take "tasks" as the basic elements of analysis, and we view the production of an organization (to produce a product or to provide a service) as the implementation of a set of interrelated tasks in a coherent way. The performance of an organization is determined by the following three factors: coordination decisions, organizational forms, and information structures.

(1) Coordination decisions

The coordination concept in this paper relates to the adjustment of the organization to exogenous disturbances and random contingencies. This concept expresses the idea that a need for coordination arises in response to exogenous disturbances to pre-set plans. Many previous studies of organizations have also explored this idea of coordination, notably Galbraith (1973).

We look at two types of task-coordination decisions. First, there are usually many attributes of a set of tasks required to produce a product or to provide a service: time, location, technical specifications such as size, weight and bits, etc. A product or a service is completed only if characteristics of each attribute among a set of tasks are matched ("attribute fit," as referred to by Milgrom and Roberts, 1992). When there is a shock affecting an attribute in one task, the attribute in other tasks must be adjusted to achieve matching. Second, there is a need for coordinating allocation of resources among tasks. It is important to make efficient use of resources within an organization. For example, when a shock affects capacity (say a breakdown) at a production line, resulting from a delivery failure by a supplier or an unusual number of absentee workers, reallocation of resources is then needed in order to ensure smoothness in the production process.

Therefore, coordination decisions involve adjusting attributes of tasks on the one hand, and reallocating resources for different tasks on the other. In the team theoretical framework, the coordination problem becomes non-trivial only when there are random contingencies, which we call exogenous shocks. This is because without exogenous shocks affecting either attributes or capacities, an organization can design a pre-set program – a "plan" – to implement all the tasks. Such a plan becomes inadequate when information is changing fast, even when the incentive problem is not present.

Specifically, we assume that there are two elementary tasks (x_m^E, x_s^E) for producing E and two elementary tasks (x_m^F, x_s^F) for producing F. The payoff function to the organization can be written as

$$X = F(x_m^E, x_s^E, x_m^F, x_s^F) = f(x^E(x_m^E, x_s^E), x^F(x_m^F, x_s^F)),$$

where f is symmetric and non-decreasing in (x^E, x^F). For example,

$$X = f(x^E, x^F) = ((x^E)^{1/a} + (x^F)^{1/a})^a, a = (1, \infty].$$

In particular, we will analyze two special cases as examples: linear payoff function$X = x^E + x^F$ (when $a = 1$) and Leontieff payoff function $x = \min x^E, x^F$ (when $a = \infty$).

Each elementary task has two dimensions: attribute and quantity, that is,

$$\begin{aligned}
x_m^E &= (a_m^E + \varepsilon_m^E, q_m^E + \eta_m^E) \\
x_s^E &= (a_s^E + \varepsilon_s^E, q_s^E + \eta_s^E) \\
x_m^F &= (a_m^F + \varepsilon_m^F, q_m^F + \eta_m^F) \\
x_s^F &= (a_s^F + \varepsilon_s^F, q_s^F + \eta_s^F).
\end{aligned}$$

Here, ε_i^j is the shock to attribute a_i^j, and η_i^j is the shock to quantity q_i^j.

Each elementary task has two independent attributes that must be matched to those of the other elementary task. Consider the pair (x_m^E, x_s^E). The first attribute of x_m^E must match the first attribute of x_s^E and similarly for the second attribute.

$$\begin{aligned} x^E &= M^E(a_m^E + \varepsilon_m^E, a_s^E + \varepsilon_s^E) g(q_m^E + \eta_m^E, q_s^E + \eta_s^E) \\ x^F &= M^F(a_m^F + \varepsilon_m^F, a_s^F + \varepsilon_s^F) g(q_m^F + \eta_m^F, q_s^F + \eta_s^F) \end{aligned}$$

where g is a usual production function, for example, a Leontieff function, and M is a matching (or fit) function taking the following form:

$$M(y,z) = \begin{cases} 1 & \text{if } y \equiv z(\text{matching}) \\ \alpha < 1 & \text{otherwise (no matching).} \end{cases}$$

Notice that our specification of the matching function exhibits different a kind of complementarity than Leontieff technology $g(x_m^E, x_s^E) = \min\{x_m^E, x_s^E\}$. Leontieff function is a supermodular function, but the matching function M in general is not.[2]

Coordination decisions in response to attribute shocks are decisions of attribute adjustments d_i^j $(i = m, sandj = E, F)$ for the purpose of matching. In order to make the coordination problem non- trivial, we assume that if for example a shock ε_m^E occurs to the first attribute of x_m^E, it is too costly to readjust that attribute to the initial plan, so that the corresponding attribute of x_s^E must be adjusted in order to obtain attribute matching (examples are given in Section 3). To simplify the modelling and also for the sake of consistency, we assume that only one of the two attributes of an elementary task may be subject to a shock. Therefore, if the first attribute of x_m^E is subject to exogenous shocks, then the first attribute of x_s^E must be adjusted to match the first attribute of x_m^E. If the second attribute of xsE is subject to exogenous shocks, then the second attribute of x_m^E must be adjusted to match the second attribute of x_s^E. We also assume for the sake of simplicity that the attribute shocks $\varepsilon_m^E, \varepsilon_s^E, \varepsilon_m^F, \varepsilon_s^F$ take either the value of 0 or 1. Perfect matching is then achieved only when the adjustment decision for the corresponding attribute of the elementary task matches the shock, i.e. $d_s^E = \varepsilon_m^E$. The action of attribute adjustment may require a cost c per non-zero adjustment d_i^j. The matching function is given by:

$$\begin{aligned} M^E &= \begin{cases} 1 & \text{if } d_s^E = \varepsilon_m^E \text{ and } d_m^E = \varepsilon_s^E; \\ \alpha & \text{otherwise.} \end{cases} \\ M^F &= \begin{cases} 1 & \text{if } d_s^F = \varepsilon_m^F \text{ and } d_m^F = \varepsilon_s^F; \\ \alpha & \text{otherwise .} \end{cases} \end{aligned}$$

[2] A function $g(x,y)$ is supermodular if $g(x', y' - g(x, y') \geq g(x', y) - g(x, y)$ for all $x' \geq x$ and $y' \geq y$. Consider matching function $M(x, y) : M(1, 1) = M(2, 2) = M(3, 3) = 1$ and otherwise 0. It is easy to see that $M(x, y)$ is not supermodular for any possible order on the set $\{1, 2, 3\}$.

Capacities are initially all normalized to 1 when there is no capacity shock (a "pre-set" plan). Let $\eta(\leq 1)$ be the size of the capacity shock, that is, η of capacity is lost under the shock. Coordination decisions are decisions of capacity transfers t_i^j ($i = m, s$ and $j = E, F$) through resource reallocation for the purpose of production smoothing. We assume that resources used for achieving the task x_m^E and x_m^F (x_s^E and x_s^F) are perfect substitutes, possibly after some costly adjustment. The assumption of symmetry of $f(x^E, x^F)$ implies that it is optimal to reallocate resources so as to equalize production of x^E and x^F (only in the special case of linear payoff function $X = x^E + x^F$ where no smoothing is needed). Capacity adjustment may also incur adjustment cost k per unit of capacity transferred.

There is a fundamental difference in the nature of these two basic adjustment decisions. Adjusting to attribute shocks means preserving the complementarity between tasks. Adjusting to capacity shocks means organizing the substitution of resources among tasks so as to preserve optimal resource allocation.

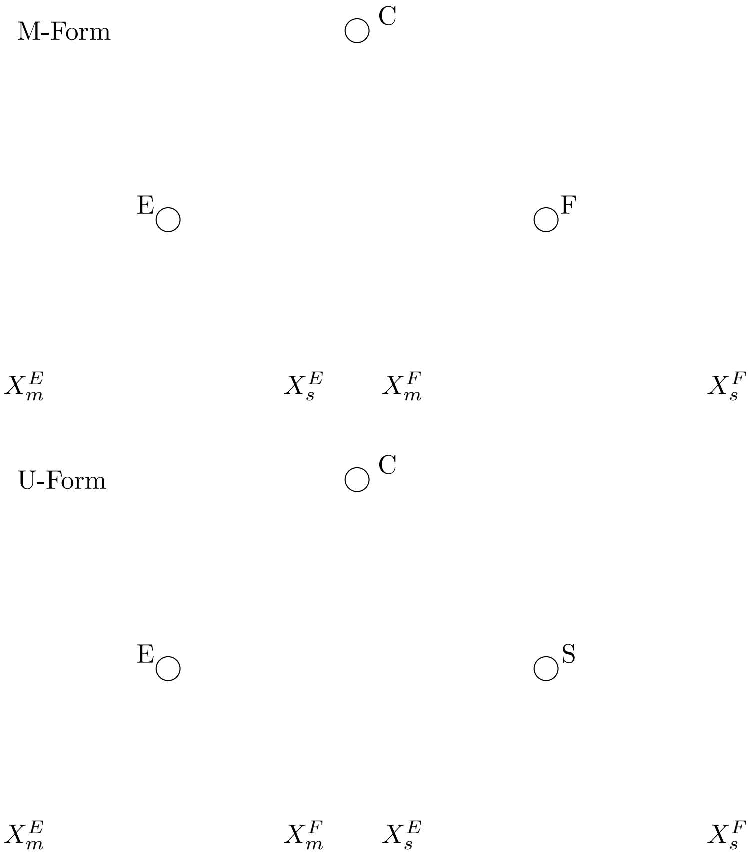
(2) Organizational forms

Coordination within an organization is affected by organizational forms along two dimensions. The first is the grouping of tasks into units (Figure 1). Among the set of elementary tasks, some tasks are more complementary to each other, and some tasks are more similar so that resources are more easily substitutable between these tasks. We call an organization a U-form if similar tasks are grouped together into one unit. This organizational form is often associated with task specialization, functional principles, process focus, etc. In contrast, in an M-form organization, complementary tasks are grouped into one unit. This organizational form is more often associated with "self-contained" divisions, geographic principles or product focus. In our definition, U-form and M-form are general categories of organizational forms and each of them may contain many different sub-forms. For example, an M-form organization can be designed by the principles of geography, product, or technology, respectively. Under our simple specification, only one M-form and one U-form organization are possible.

One factor affecting the performance of an organization is the possible gain from specialization when a person or unit specializes in the same or similar tasks. We assume that under such a specialization, if all attributes are perfectly matched and there is no capacity shock, $g(1, 1) = \beta$ and otherwise $g(1, 1) = 1$. Because the idea of specialization is well understood, we will assume $\beta = 1$ for the main part of the paper.

The second dimension concerns the allocation of authority for coordination. Centralization allocates major coordination decisions to the central office, while decentralization allocates those decisions to the units, which are run by managers or workers.

FIG. 1. Organizational Forms: M-Form vs. U-Form



We are interested in coordination decisions within the four following organizational forms:

	U-Form	M-Form
Centralization	Centralized U-form	Centralized M-form
Decentralization	Decentralized U-form	Decentralized M-form

For attribute shocks adjustment, under centralization, the center chooses all d_i^j ($i = m, s$ and $j = E, F$) to maximize the expected payoff to the organization subject to its information constraint. Under decentralization, each unit chooses d_i^j ($i = m, s$ under M-form and $j = E, F$ under U-form) to maximize the expected payoffs to the organization subject to its information constraint and taking the decision of the other unit as given.

For capacity shock adjustment, under centralization, the center chooses all t_i^j ($i = m, s$ and $j = E, F$) to maximize the expected payoff to the organization subject to its information constraint. Under decentralization, each unit chooses t_i^j ($i = m, s$ under M-form and $j = E, F$ under U-form) to maximize the expected payoffs to the organization subject to its information constraint and taking the decision of the other unit as given.

(3) Information structures

Coordination involves receiving information about exogenous shocks and taking action accordingly. We follow the Hayekian assumption about local information. The manager of a unit has better local information about his unit than his superiors or the managers of other units because vertical and horizontal communication is not perfect. On the other hand, the superior has better global information about all units than any of his subordinates, because horizontal communication is less frequent than vertical communication within an organization.

Under the above assumptions, information structures in our model are endogenous depending on the organization forms – grouping of the tasks and allocation of authority. Specifically, under the decentralized M-form, the manager of unit E has perfect local information about $(\eta_m^E, \varepsilon_s^E)$ and $(\eta_m^E, \varepsilon_s^E)$, but has no information about $(\varepsilon_m^F, \varepsilon_s^F)$ and (η_m^F, η_s^F). Similarly, the manager of unit F has perfect local information about $(\varepsilon_m^F, \varepsilon_s^F)$ and (η_m^F, η_s^F), but has no information about $(\varepsilon_m^E, \varepsilon_s^E)$ and (η_m^E, η_s^E). Under the decentralized U-form, the manager of unit M has perfect local information about $(\varepsilon_m^E, \varepsilon_m^F)$ and (η_m^E, η_m^F), but has no information about $(\varepsilon_s^E, \varepsilon_s^F)$ and (η_s^E, η_s^F), and the manager of unit S has perfect local information about $(\varepsilon_s^E, \varepsilon_s^F)$ and (η_s^E, η_s^F), but has no information about $(\varepsilon_m^E, \varepsilon_m^F)$ and (η_m^E, η_m^F).

We made the assumption that communication within a unit is perfect, but cross-unit communication is imperfect for the following reasons. First, perfect communication requires direct involvement of activities. Therefore, when activities are shared by group members within a unit, the communication between the members is good. But communication between the members across groups through methods such as phone calls, faxes, memos, meetings, etc. only transmits reduced information because the members do not involve with the same activities. Second, people in different units may speak different languages (e.g., engineering language differs from marketing language and even the language used by empirical economists sometimes differs from that of theoretical economists), and/or they may have different knowledge and might interpret the same message differently. All of these reasons will make communication across units imperfect. On the other hand, the center is more involved with each unit's operation, and thus communication between it and the units is better than the communication between units. For the sake of simplicity, we assume that there is no horizontal communication between units and the center receives imperfect information about shocks in all units.

3. EXAMPLES

In this section, we give four examples of the model. The background of the examples is from the literature of business organizations, military organizations and centrally planned economies.

Example 1 (multi-product corporations):

This example reflects the organizational problems faced by Du Pont and General Motors discussed by Chandler (1962) and Williamson (1976). Suppose a large corporation organizes manufacturing function (M) and sales function (S) with two major products, explosives (E) and fertilizer (F) (in the case of Du Pont), or popular cars (P) and luxury cars (L) (in the case of GM). There are two ways of organizing the tasks related to the functions and the products within the corporation. Under the U-form, there are two functional departments under the central office: the manufacturing department and the sales department. Each department is specialized in one function to deal with all products of the corporation, e.g. explosives (E) and fertilizer (F). The manufacturing department has two workshops to produce explosives and fertilizer, and the sales department has two shops to sell explosives and fertilizer. Under the M- form, there are two product divisions under the central office: the explosive division and the fertilizer division. Each division has its own functional shops – the manufacturing shop and the sales shop.

There are two attributes in this example. One attribute is about types and specifications of products demanded by customers. The shock in this attribute is received by the sales shop. If the information is transmitted to the manufacturing shop, adjustment of product attribute is needed to meet customers' need. The other attribute is about types and specifications of the products produced, for example, switching raw material from petrol to coal which changes attributes of final products. Shocks in this attribute are received by the manufacturing shop. When the attribute shock signal is transmitted to the sales shop, adjustment in advertising is needed to convince customers. In both cases, attribute adjustment may incur costs.

In this example, manufacturing capacity relates to the E and F production capacity and sales capacity relates to the quantities of successful sales. A partial breakdown of an assembly line is a capacity shock in manufacturing and an increase or decrease in demand contributes to capacity shocks in sales. Inventory is used as a buffer to reduce the impact of capacity shocks. When different final products are highly substitutable, final product inventory is used. But when final products are not highly substitutable, semi-products which are can be identified and used as a buffer, for example nitric acid and other chemicals are used for making both explosives and fertilizer. Each shop transfers a proportion of semi-products to inventories if there is no capacity shock in that shop. The cost of capacity adjustment includes (i) cost from adjusting attributes of semi-products in an inventory; (b) cost of inventory maintenance; and (c) transportation cost.

Example 2 (car manufacturing):

This example emphasizes coordinating production activities within the manufacturing sphere. A firm makes two types of cars: the popular car (P), x^P, and the luxury car (L), x^L. There are two complementary parts for each car to be produced: body (B), x_b, and engine (E), x_e. There are two ways of organizing the production.

Under a U-form organization, one body plant produces all the bodies for the two types of cars, x_b^P and x_b^L, and one engine plant produces all the engines for the two types of cars, x_e^P and x_e^L. The two types of cars, x^P and x^L, are assembled in the same assembly line at the headquarters of the firm. Under an alternative M-form organization, division P (e.g. Chevrolet in GM) produces popular cars including body and engine; and division L (e.g. Cadillac in GM) produces luxury cars including body and engine.

Attributes here are technical specifications of body and engine for each type of car such as size, strength, weight, rigidity, etc. These technical specifications must match each other to make a quality car. Attributes are designed to match each other in the blueprints of the products. Attribute shocks can be technical changes on attributes to body and/or engine, for example, the size of the engine has to be reduced due to an oil crisis, or the type of material used for the body has to be changed due to environmental regulations. Attribute shocks can also be due to changes in consumer tastes regarding attributes of bodies and engines.

In this example, capacities refer to the quantities of bodies and engines produced for each type of car. Shocks can come from a change in demand for one type of car or from a change in quantities of supply of body or engine parts for either type of car due to technical reasons or strike by workers. Inventories of semi-products of bodies and engines are used as buffers to deal with capacity shocks. Here, semi-products are substitutable between different types of bodies or between different types of engines. But the perfectness of the substitutability varies. The aspects of adjustment costs in this example are similar to those in example 1.

Example 3 (military operations – the Normandy Landing):

In this example, there are two landing fronts: North front (N) and South front (S). There are also two types of complementary forces: air force (A) and navy-marines (M). There are two ways of organizing the military force for a landing operation.

Under the U-form organization, one unit controls all the air forces, x_a, i.e., the air forces in the North front and in the South front, x_a^N and x_a^S. Another unit controls all the navy-marines, x_m, which includes the navy-marines in the North front and in the South front, x_m^N and x_m^S. Under an alternative M-form organization, one unit controls all the forces in the North front, x^N, which includes air force and navy-marine, x_a^N and x_m^N. Another unit controls all the forces in the South front, x^S, which includes air force and navy-marines, x_a^S and x_m^S.

In the case of centralization, the commander in chief is responsible for all the coordinating tasks between A and M, and between N and S. In the case of decentralization, A and M generals (U-form) or N and S front generals (M-form) are responsible for coordinating tasks.

The attributes of the tasks include the location of bombing and landing, timing of attack, formation of troops, firing specifications of troops, etc. Mis-matching of the attributes between the air force and navy-marines will cause the failure of the operation. The operation plan must match all attributes ex ante, even though there are many reasons for attribute shocks to occur. For example, a weather change may delays an air force operation, so a change in landing time is called for. An unexpected enemy move or deployment may make it necessary to change the landing location of navy-marines, which in turn might require a change in bombing location and firing specifications by the air force.

Capacities refer to the volume of firing and bombing, and quantities of airplanes and navy-marines on both North and South fronts. Capacity shocks occur when there is a reduction of existing capacity due to unexpected casualty or unexpected bad weather, or when there is an increase in demand for more capacity due to unexpected reinforcement of the enemy. To deal with capacity shocks, reserve forces are often used. A proportion of air force and navy-marines on the North and South fronts are reserved if there is no capacity shock on that front.

Example 4 (centrally planned economies):

This example is taken from the comparative studies of transition economies by Qian and Xu (1993). Suppose there are two regions in an economy, East (E) and West (W), and two sectors, steel (S) and machine-building (M). The steel industry demands machineries from the machinery industry and the machine industry needs raw material from the steel industry.

Under a U-form economy (e.g., the Soviet economy), there are two ministries, S and M. All steel-making firms are managed by the S ministry, producing x_s. All the machine-building firms are managed by the M ministry, producing x_m. Under an M-form (e.g., the Chinese economy), there are two regional governments, E and W. Each regional government manages firms of both industries in the region. In region E, the products are x_s^E and x_m^E, and in region W the products are x_s^W and x_m^W.

In the case of centralization, the central government is responsible for all coordination. In the case of decentralization, ministries (U-form) or regional governments (M-form) are responsible for coordination.

The attributes of the tasks in the economy are related to the technical specifications and delivery time of the products S and M. Initially the attributes are designed to match each other in the economic plan. Attribute shocks in the economy include both demand and supply shocks on attributes of S and/or M, for example, a different type of steel is supplied because the original type is exported, or an imported new technology in steel industry requires a new type of digital machinery.

Capacity shocks in the economy include changes in demand for S and/or M and changes in production capacity of S and/or M. For example, tightening up the credit policy or opening to foreign trade may cause such changes. Inventories are used as buffers to deal with capacity shocks. Suppose each M factory produces semi-products and final products. Semi-products of the similar machines are substitutable between different machine-building factories. Each M factory transfers a proportion of semi-products to inventory if there is no capacity shock in that region. Similarly, each S factory transfers a proportion of S products to inventory if there is no capacity shock in that region.

4. COORDINATION UNDER ATTRIBUTE SHOCKS

We assume that attribute shocks $\varepsilon_m^E, \varepsilon_s^E, \varepsilon_m^F, \varepsilon_s^F = 0$ or 1 and the probabilities of being 1 are $\rho_m^E, \rho_s^E, \rho_m^F, \rho_s^F$ respectively. Shocks are independent and all ρ_i^j's are less than 1/2.

4.1. The Case without Adjustment Costs

Under decentralization, we use the Nash equilibrium concept and note that under the team theory assumption, the objective of the managers in two units are the same as the organizational objective (this is the same as "person-by-person satisfactory" decision rules used by Marschak and Radner, 1972). The role of the center under decentralization is restricted to equilibrium selection if there are multiple equilibria. Therefore only the equilibrium generating the highest expected payoff to the organization will be chosen.

PROPOSITION 1. *Suppose there is no gain from specialization* ($\beta = 1$). *Then, the centralized U-form and M-form are identical and* $EX_{MD} \geq EX_C \geq EX_{UD}$.

Proof. First consider the decentralized U-form. Because shocks are independent, an attribute shock in one unit provides no information on attribute shocks in the other unit. Since the loss function is 0 only if the two attributes of the corresponding elementary tasks of the same product are all matched, the adjustment decision in one unit is independent of the decision in the other unit. Because the probability of shocks is less than 1/2, the optimal strategy for each unit is "doing nothing," maintaining the status quo. That is, $d_i^j \equiv 0$ is a unique Nash equilibrium, in fact, it is a dominant strategy equilibrium.

Next consider the case for the decentralized M-form. Because unit managers have perfect information about attribute shocks and the authority to coordinate, perfect coordination is the equilibrium. Therefore the decentralized M-form achieves the first best.

Finally, since the decentralized M-form achieves the first best and the decentralized U- form achieves the minimum, centralization must be in between. ∎

Intuitively, the decentralized M-form can always mimic the information structure of centralization as far as attribute adjustments are concerned; therefore the former can do as well as the latter. One the other hand, since centralization can always choose to do nothing just like the decentralized U-form, centralization can do at least as well as the decentralized U-form.

When there is possible gain from specialization ($\beta \geq 1$), the equilibrium under the decentralized U-form is still "doing nothing" and that under the decentralized M-form is still "full adjustment." Under the centralized U-form, the manager in each unit specializes in one task and the productivity of carrying out that task is $\beta (\geq 1)$. The other task of the unit managers is communication with the center in case of attribute shocks. The task of the center is to make coordination decisions when receiving imperfect signals. Under the centralized M-form, managers in each unit also communicate with the center regarding any attribute shocks, but there is no gain from specialization. Because the signal received by the center is the same under both the U-form and M-form, the centralized U-form weakly dominates the centralized M-form because of the gain from specialization.

Under centralization, the center receives imperfect signal s_i^j ($i = m, s$, and $j = E, F$) with

$$\begin{array}{ll} \text{Prob}(s_i^j = 1|\varepsilon_i^j = 1) = \lambda_i^j; & \text{Prob}(s_i^j = 0|\varepsilon_i^j = 1) = 1 - \lambda_i^j \\ \text{Prob}(s_i^j = 1|\varepsilon_i^j = 0) = 1 - \lambda_i^j; & \text{Prob}(s_i^j = 0|\varepsilon_i^j = 0) = \lambda_i^j, \end{array}$$

where $\lambda_i^j \geq 1/2$. Therefore, $s_i^j = 1$ (or 0) is a signal for $\varepsilon_i^j = 1$ (or 0).

PROPOSITION 2. *Under centralization, for all non-decreasing continuous functions $f(x^E, x^F)$, the optimal decision rule by the center for product i ($i = E, F$) is given by:*

$$\begin{array}{l} d_s^i(s_m^i = 1) = 1 \text{ and } d_s^i(s_m^i = 0) = 0 \text{ if } \lambda_m^i + \rho_m^i > 1; \\ d_s^i(s_m^i = 1) = 0 \text{ and } d_s^i(s_m^i = 0) = 0 \text{ if } \lambda_m^i + \rho_m^i < 1; \\ d_m^i(s_s^i = 1) = 1 \text{ and } d_m^i(s_s^i = 0) = 0 \text{ if } \lambda_s^i + \rho_s^i > 1; \\ d_m^i(s_s^i = 1) = 0 \text{ and } d_m^i(s_s^i = 0) = 0 \text{ if } \lambda_s^i + \rho_s^i < 1. \end{array}$$

Proof. See Appendix. ▌

Using conditional probabilities and the optimal decision rules obtained above, we can calculate the expected output of product i under the centralized U-form:

$$\begin{array}{rll} Ex^i = & \beta\{(1-\rho_m^i)(1-\rho_s^i)(1-\alpha)+\alpha\} & \text{if } \lambda_m^i + \rho_m^i < 1 \text{ and } \lambda_s^i + \rho_s^i < 1; \\ = & \beta\{\lambda_m^i \lambda_s^i (1-\alpha)+\alpha\} & \text{if } \lambda_m^i + \rho_m^i > 1 \text{ and } \lambda_s^i + \rho_s^i > 1; \\ = & \beta\{\lambda_s^i (1-\rho_m^i)(1-\alpha)+\alpha\} & \text{if } \lambda_m^i + \rho_m^i < 1 \text{ and } \lambda_s^i + \rho_s^i > 1; \\ = & \beta\{\lambda_m^i (1-\rho_s^i)(1-\alpha)+\alpha\} & \text{if } \lambda_m^i + \rho_m^i > 1 \text{ and } \lambda_s^i + \rho_s^i < 1. \end{array}$$

In particular, when $\lambda_m^i = \lambda_s^i = 1$ (i.e., perfect information), the expected output $Ex^i = \beta$; when $\rho_m^i = \rho_s^i = 0$ (i.e., no possible shocks), the expected output $Ex^i = \beta$; and when $\lambda_m^i = \lambda_s^i = 1/2$ (i.e., no information), the expected output $Ex^i = \beta\{(1-\rho_m^i)(1-\rho_s^i)(1-\alpha)+\alpha\}$.

In our framework, centralization/decentralization and the U-form and M-form are two independent dimensions of organizational features. If $\beta > 1$, there are only two undominated organizational forms, they are the centralized U-form and the decentralized M-form. The former has the advantage of specialization and the latter the advantage of lower costs from coordination failure. This provides an explanation of why in reality one observes that the U-form is often associated with centralization and the M-form with decentralization.

PROPOSITION 3. *There exists $\beta^*(\rho, \lambda, \alpha)$ such that the decentralized M-form is preferred to the centralized U-form if and only if $\beta \leq \beta^*(\rho, \lambda, \alpha)$.*

Proof. Under the centralized U-form, the optimal decision rule is independent of β. When $\beta = 1$, the decentralized M-form dominates the centralized U-form. When β is very large, the centralized U-form dominates the decentralized M-form. Because the payoff function of the decentralized U-form is a non-decreasing function of β and that of the decentralized M-form is independent of β, such an β^* exists. ∎

Example (symmetric shocks with a linear payoff function):
Consider the symmetric case in which $\lambda_i^j = \lambda$ and $\rho_i^j = \rho$ for all i and j and the linear payoff function $f(x^E, x^F) = x^E + x^F$. We obtain the following expected payoffs to the organization:

Centralized U-form :	$2\beta \max\{\lambda^2 + (1-\lambda^2)\alpha, (1-\rho)^2 + (1-(1-\rho)^2)\alpha\}$;
Centralized M-form :	$2 \max\{\lambda^2 + (1-\lambda^2)\alpha, (1-\rho)^2 + (1-(1-\rho)^2)\alpha\}$;
Decentralized U-form :	$2\beta[(1-\rho)^2 + (1-(1-\rho)^2)\alpha]$;
Decentralized M-form :	2.

It is easy to see that the decentralized M-form is preferred to the centralized U-form if and only if $\beta \leq \beta^*$, where

$$\beta^* = 1/\{\max\{\lambda^2 + (1-\lambda^2)\alpha, (1-\rho)^2 + (1-(1-\rho)^2)\alpha\}\},$$

and β^* is an increasing function of ρ and a decreasing function of λ and α.
In particular, if $\beta = 1$,

$$EX_M D = 2 \geq EX_C = 2\max\{\lambda^2, (1-\rho)^2\} \geq EX_{UD} = 2(1-\rho)^2,$$

where the first equality holds if and only if $\lambda = 1$ or $\rho = 0$, and the second equality holds if and only if $\lambda + \rho < 1$.

Therefore, the decentralized M-form has a comparative advantage if the gain from specialization is not high (β is small), shocks are more likely (ρ is large), information quality is poor (λ is small), or the loss from coordination failure (mismatching) is severe (α is small). Otherwise, the centralized U-form is better. This model also shows that if there is a sudden collapse of centralized coordination, the decentralized M-form performs better than the decentralized U-form if and only if

$$\beta \leq 1/[(1-\rho)^2 + (1-(1-\rho)^2)\alpha].$$

A smaller β, smaller α and larger ρ all make the decentralized U-form less desired.

4.2. The Case with Adjustment Costs

Suppose that the cost of adjusting one attribute is c and the cost of adjusting two attributes is $2c$. We also assume from now on that $\beta = 1$.

PROPOSITION 4. *For all $c > 0$, we have $EX_{MD} \geq EX_C \geq EX_{UD}$. Furthermore, for continuous payoff function f, if all $\rho_i^j > 0$ and c is not too large, as all λ_i^j's $\to 1$, EX_C converges to EX_{MD} and $EX_{MD} \geq EX_C > EX_{UD}$.*

Proof. We first note that if no adjustment is optimal under $c = 0$, it must also be optimal for any $c > 0$. Therefore under the decentralized U-form, $d_i^j \equiv 0$ is still a unique Nash equilibrium, which achieves only the minimum payoff. But the decentralized M-form always has perfect information and it achieves the first best payoff.

Given $c > 0$, as all λ_i^j's approach $1, \lambda + \rho > 1$ because $\rho > 0$. By Proposition 2, the optimal decision under centralization does not change. When f is continuous, the net payoff under centralization is continuous and will be arbitrarily close to that of the decentralized M-form, the first best. As long as c is not large enough so that $EX_{MD} > EX_{UD}$, centralization will dominate the decentralized U-form as all λ_i^j's approach 1. ∎

Combining Propositions 1 and 4, introduction of adjustment costs has no effect on the ranking of the decentralized M-form, centralization, and the decentralized U-form under attribute shocks. This is because the equilibrium under the decentralized U-form is always "adjust nothing" for all c, and the decentralized M-form can always do as well as the centralized organization.

Example (symmetric shocks with a linear payoff function):

When $\lambda_i^j = \lambda$ and $\rho_i^j = \rho$ and $f(x^E, x^F) = x^E + x^F$, we can characterize in more detail the solution in alternative organizational forms.

LEMMA 1. *(1) The optimal decision under the decentralized U-form is no adjustment for all c.*

(2) The optimal decision under the decentralized M-form is given by (i) if $c > 1 - \alpha$, no adjustment is made; (ii) if $c < 1 - \alpha$, one adjustment is made when there is one shock; and (iii) if $c < (1 - \alpha)/2$, two adjustments are made when there are two shocks.

(3) Under centralization, if $\lambda + \rho < 1, d = (0, 0)$ is optimal. If $\lambda + \rho > 1$ and $\alpha = 0$, there exist $c_1 \leq c_2 \leq 1$ such that the optimal decision rule is (i) if $c > c_2$, no adjustment is made for all signals; (ii) if $c_1 < c < c_2$, one adjustment is made when the signal shows one shock and no adjustment is made when the signal shows two shocks; and (iii) $c < c_1$, one adjustment is made when the signal shows one shock and two adjustments are made when the signal shows two shocks.

Proof. See Appendix. ▮

PROPOSITION 5. *Let $\alpha = 0$. Comparing the decentralized U-form, M-form and centralization, we have*
(i) if $c > 1, EX_{MD} = EX_C = EX_{UD}$;
(ii) if $c_2 < c < 1, EX_{MD} > EX_C = EX_{UD}$; and
(iii) if $c < c_2, EX_{MD} > EX_C > EX_{UD}$.

Proof. Applying Lemma 1:
(i) When $c > 1$, no adjustment is made under any organization, so $EX_{MD} = EX_C = EX_{UD}$.
(ii) When $c_2 < c < 1$, no adjustment is made under centralization, therefore $EX_C = EX_{UD}$. But one adjustment will be made if one shock is observed under the decentralized M-form, which gives a higher expected payoff, hence $EX_{MD} > EX_C = EX_{UD}$.
(iii) When $c < c_2$, some adjustment will be made under centralization, which is better than UD. However, centralization can never do better than the decentralized M-form because of imperfectness of signal. ▮

Therefore, in this example, as the adjustment cost c increases, centralization first stops making adjustment in response to the signals, which converge to the decentralized U-form. As the adjustment cost continues to increase, then the decentralized M-form also stops making adjustment.

5. COORDINATION UNDER CAPACITY SHOCKS

The capacity shocks $\eta_m^E, \eta_s^E, \eta_m^F, \eta_s^F = 0$ or η happen with probability of 1 being $\sigma_m^E, \sigma_s^E, \sigma_m^F, \sigma_s^F$. We also assume that shocks are independent and σ_i^j's are less than 1/2.

5.1. The Case without Adjustment Costs

PROPOSITION 6. *Let $g(x_m, x_s) = \min\{x_m, x_s\}$. For all symmetric, non-decreasing and concave functions $f(x^E, x^F), EX_{MD} = EX_{UD} \geq EX_C$.*

Proof. We first note that equalization of the capacities for two similar tasks is desirable because f is concave and symmetric and $g(x_m, x_s) = \min\{x_m, x_s\}$. Under the decentralized U-form and a symmetric, non-decreasing and concave function $f(x_E, x_F)$, equalization of the capacities is achieved by the strategy { transfer $\eta/2$ when only one shock is observed, and transfer nothing otherwise}. Under the decentralized M-form, the above outcome can be replicated by the following strategy: { always transfer $\eta/2$ of the capacity to the other unit whenever no shock is observed}. Because signals are noisy, centralization can never do better than the first best, which both the decentralized M-form and U-form can achieve. ∎

Comparing Proposition 6 with Proposition 1, a natural question arises: Why can the decentralized M-form replicate the first best of the decentralized U-form under capacity shocks, but the decentralized U-form can't replicate the first best of the decentralized M-form under attribute shocks? Two basic assumptions about the technology make the attribute matching fundamentally different from capacity substitution. First, the matching function takes the form in which any mis-matching will lead to the collapse of production. Second, whenever one attribute of an elementary tasks changes, the attribute of the other elementary task has to adjust to make a match. Therefore, information about shocks in one task is essential in making a right adjustment in the other task. But the same is not true in capacity shocks even if, as we have assumed, the technology is one of Leontieff: $g(x_m, x_s) = \min\{x_m, x_s\}$, that has some degree of complementarity. With the possibility of transfers of resources for substitution, perfect information is not essential in making partial right decisions in capacity shocks.

Therefore, information requirements for achieving coordination under decentralization are different when there are attribute or capacity shocks. The results of our analysis on capacity shocks show that transfers to inventories can be a substitute for communication. But the same does not apply to attribute shocks simply because there is nothing to substitute.

However, the above results are derived by assuming that the cost of transferring is zero. When these transfers are costly, we should not expect the equivalence of the decentralized M-form and U-form.

5.2. The Case with Adjustment Costs

Recall that introducing adjustment costs does not change the ranking of organizational forms in the case of attribute shocks. But the same can't be said in the case of capacity shocks. Suppose that the unit adjustment cost in capacity transfer is k. This cost is independent of organizational forms, in particular, it should not be interpreted as a transportation cost. It can be regarded as a cost associated with re-packaging, for example.

PROPOSITION 7. *Suppose $\sigma_i^j > 0$, and $k > 0$, but is not too large. If f is continuous, as all μ_i^j's approach 1, EX_C converges to EX_{UD} and $EX_{UD} \geq EX_C > EX_{MD}$.*

Proof. Assume μ_i^j's are arbitrarily close to 1. Then the gross payoff under centralization will be arbitrarily close to that of the decentralized U-form, the first best. However, the differences between the costs of adjustment under the decentralized M-form and centralization are not arbitrarily close to each other, as the cost of adjustment under the decentralized M-form is independent of μ_i^j's. If $k > 0$ but is not large enough, then the difference in costs will not be arbitrarily close to 0, so that centralization will dominate the decentralized M-form. ▌

Although the decentralized U-form is never dominated, the ranking between the decentralized M-form and centralization is not always as Proposition 7 suggests, because the information structure of the two can't be ranked. We show this by examining the following example.

Example (one shock with Leontieff payoff function):

Consider the following example:

(i) There is only one possible symmetric shock as follows:

$r_1 : (\eta, 0, 0, 0)$ with probability $\sigma \leq 1/8$
$r_2 : (0, \eta, 0, 0)$ with probability $\sigma \leq 1/8$
$r_3 : (0, 0, \eta, 0)$ with probability $\sigma \leq 1/8$
$r_4 : (0, 0, 0, \eta)$ with probability $\sigma \leq 1/8$
$r_5 : (0, 0, 0, 0)$ with probability $1 - 4\sigma \geq 1/2$.

(ii) The payoff function to the organization is Leontieff $f(x^E, x^F) = \min\{x^E, x^F\}$. The assumption of $g(x_m, x_s) = \min\{x_m, x_s\}$ is maintained.

Under centralization, assume that there are five signals $s_i, i = 1, \cdots, 5$, with

$$P(s_i|r_i) = \mu; \quad \text{and}$$
$$P(s_j|r_i) = \nu, i \neq j,$$

where $\nu = (1 - \mu)/4$.

LEMMA 2. *(1) The optimal decision under the decentralized U-form is $t = 0$ if $k > 1$ and $t = \eta/2$ if $k < 1$ with the expected payoff*

$$EX_{UD} = \begin{cases} 1 - 4\sigma\eta & \text{if } k > 1 \\ 1 - 2\sigma\eta(1 + k) & \text{if } k < 1. \end{cases}$$

(2) The optimal decision under the decentralized M-form $t = 0$ if $k > \sigma/(1 - 2\sigma)$ and $t = \eta/2$ if $k < \sigma/(1 - 2\sigma)$ with the expected payoff

$$EX_{MD} = \begin{cases} 1 - 4\sigma\eta & \text{if } k > \sigma/(1 - 2\sigma) \\ 1 - 2\sigma\eta - 2k\eta(1 - 2\sigma) & \text{if } k < \sigma/(1 - 2\sigma). \end{cases}$$

(3) The optimal decision under centralization is $t = 0$ if $k > \underline{k}$ or if s_5 is observed, and $t = \eta/2$ if $k < \underline{k}$ and if $s_i (i = 1, 2, 3, 4)$ is observed, where

$\underline{k} = 1 - 2\nu(1-2\sigma)/(\mu\sigma + \nu(1-\sigma))$. *The expected payoff is*

$$EX_C = \begin{cases} 1 - 4\sigma\eta, & \text{if } k > \underline{k} \\ 1 - (\eta/2)[(1-\mu+(5-\mu)\sigma] - (k\eta/2)[4\mu\sigma + (1-\mu)(1-\sigma)], & \text{if } k < \underline{k}. \end{cases}$$

Proof. See Appendix. ▮

The decentralized U-form achieves the first best in dealing with capacity shocks, hence it weakly dominates other organizational forms for all k.

PROPOSITION 8. *Comparing the decentralized U-form, M-form and centralization, we have*

(1) $EX_{UD} \geq EX_{MD}$ *with strict inequality holds if and only if* $0 < k < 1$*;*

(2) when $\mu < 1$*, (i)* $EX_{UD} > EX_C > EX_{MD}$*, if* $\sigma/(1-2\sigma) < k < 1 - 2\nu(1-2\sigma)/(\mu\sigma + \nu(1-\sigma))$*, and*

(ii) $EX_{UD} > EX_{MD} > EX_C$*, if* k *is small enough.*

Proof. See Appendix. ▮

Therefore, except for the special cases of no adjustment costs or adjustment costs being too high, the decentralized U-form strictly dominates the decentralized M-form. Although we know that the decentralized U-form achieves the first best, we are unable to rank centralization and the decentralized M-form because the decentralized M-form shifts to $t = \eta/2$ when $k < \sigma/(1-2\sigma)$ and centralization shifts to $t = \eta/2$ when $k < 1 - 2\nu(1-2\sigma)/(\mu\sigma + \nu(1-\sigma))$ which depends on μ. This may mean that inventory and communications are substitutes in the following sense: When the cost of inventory is high (i.e., k is high), the better information available under centralization regarding capacity shocks gives an advantage (Proposition 8(2)(i)). When the cost of inventory is low (k is low), even if information about capacity shocks is bad, the decentralized M-form still performs better than under centralization (Proposition 8(2)(ii)).

6. COMBINING ATTRIBUTE SHOCKS AND CAPACITY SHOCKS

Assume that attribute shocks and capacity shocks are independent. Combining the two shocks together, there are three pure cases: (1) complete centralization; (2) U-form, complete decentralization; and (3) M-form, complete decentralization.

PROPOSITION 9. *Suppose both* $c > 0$ *and* $k > 0$ *and they are not too large. When both* λ *and* μ *are close to 1,* $EX_C > EX_{UD}$ *and* $EX_C > EX_{MD}$.

Proof. Because attribute shocks and capacity shocks are independent, we can use Propositions 4 and 7. When both λ and μ approach 1, EX_C converges to $EX_M D$ under attribute shocks (the first best, by Proposition 4) and EX_C converges to EX_{UD} under capacity shocks (again the first best, by Proposition 7). But EX_{MD} only achieves the first best under attribute shocks and is bounded from the first best under capacity shocks, therefore, $EX_C \geq EX_{MD}$ as both λ and μ approach 1. Similarly, $EX_C \geq EX_{UD}$. ▮

7. EXPERIMENTS, INNOVATION, AND REFORM

Shocks in the above analysis are exogenous, and are thus more relevant to the coordination problems in "routine activities." In contrast, shocks in "innovation activities" are endogenous because uncertainty is introduced by the decision to carry out innovation. We view innovation as the process of experimentation with new ideas and the subsequent promotion of successful results. A new idea involves a change in existing attributes or the introduction of new attributes associated with possible higher outputs or lower costs. An experiment is called successful if the attributes fit to local conditions and the attributes in several tasks fit to each other, and if the outcome generates higher outputs or lower costs. Different organizational forms have different features when dealing with shocks, and therefore would carry out experiments differently. In promotion, the result of a successful experiment is imitated by other units of an organization.

We distinguish two types of innovative ideas. The first type of idea originates within the central office or laboratory of the organization, or is introduced from outside the organization. An organization may design a prototype in its R&D department or purchase a patent from another firm or laboratory. It may decide to adopt some new policies and principles which have been established outside of it (such as a new accounting system or a new tax and monetary system). For this type of idea the blueprint of innovation originates in the center. The second type of idea originates at lower levels within an organization through the use of on-site information and by trial and error. Often this type of innovation has no blueprint and many of these ideas may depend upon earlier results of other experiments. For example, the quality of cars can be improved by incremental changes on workshop floors in Japan (Aoki, 1986); productivity of manufacturing can be increased by trying different ways of assembling things (Roemer, 1993); and market-oriented reforms in China may feature sustained entry and expansion of a variety of new rural industrial firms (Qian and Xu, 1993).

Because organizational forms affect how the coordination problems are being solved, they also affect how innovations are being carried out, or not being carried out at all. An innovation pattern in an organization depends on the type of ideas (from the top or from the bottom), how tasks are grouped together (M-form or U-form), and on where any adjustments of attributes will be coordinated (centralized or decentralized). The flexibility of an organization is the feature that allows it to carry out many experiments.

Here, we assume that new ideas originate from the top because the central office or laboratory has concentrated experts who specialize in studying experiences from outside the organization, learning scientific and engineering principles, and developing new knowledge.[3] The output of the research often takes the form of "blue prints" for innovation.

The fact that the ideas or blue prints originated from the top does not necessarily imply that experiments must be completely centralized. Even if the attributes in the new idea are initially matched to each other in the blue print, these attributes may not be compatible with the local conditions such as the existing production equipment and/or organizational rules. Therefore, some adjustment of attributes must be made to fit to local conditions. But the partially adjusted attributes may not fit each other any more. Because experiments involve adjustment of attributes to fit local conditions and adjustment of attributes to fit each other, coordination of adjustment of attributes is essential to the success of experiments.

Assume that an innovation involves changes of the two attributes in the pair of elementary tasks. For simplicity, we assume that attribute 1 may not fit to local conditions for task x_m, and attribute 2 may not fit to local conditions for task x_s. If attribute 1 does not fit to local conditions, task x_m has to make an adjustment. This adjustment causes mis-matching if task x_s does not make a corresponding adjustment. A matching for attribute 1 is achieved only if task x_s makes an adjustment. Adjustment for attribute 2 is similarly defined. Let ρ' be probability that one attribute does not fit to the local conditions and adjustment must be made, and $1-\rho'$ be probability that one attribute fits to local conditions. Two attributes are

[3]In reality new ideas for innovation may come from other sources as well. Information about local environment combined with some publicly available information also generate innovative ideas from bottom. The Japanese way of improving car manufacturing and the Chinese method of agricultural and industrial reforms are examples of this approach. Due to the limitation of the space in this paper, we are not going to model this cases.

stochastically independent. We use the symmetric and linear example in Section 4 and assume that adjustment cost is zero.

A perfect matching means that each of the two attributes are matched between two tasks. Conditional on a perfect matching of attributes, the probability of success is p which gives productivity $A > 1$, the probability of failure is $1 - p$ which gives 0. We assume that $pA > 1$.

Consider a model of two periods, where the second period is a replication of the first period. The discount rate is δ. In addition, we assume that the local conditions for product E is the same as for product F.[4] Note that this assumption won't change any results for attribute shocks in section 4. An organization with a particular organizational form will decide how many experiments (0, 1, or 2) should be carried out in period 1. Let the cost of one experiment be I (which differs from adjustment costs) and the cost of reversal be R. We maintain shocks in routine activities in the situations where no experiment is carried out or the result of the experiment is copied in period 2.

If no experiment is carried out, the old design will be used in two periods. The expected payoffs are given directly by the Example in section 4.

Consider the possibility of one experiment. Let the experiment be carried in unit E under the decentralized M-form. For attribute 1, if the unit manager finds that the new attribute design on task x_m^E does not fit to local condition he first makes an adjustment for task x_m^E according to the local conditions and then makes a corresponding adjustment for task x_s^E to achieve matching in attribute 1. Similarly for attribute 2. Therefore, perfect matching is always achieved in this case. The expected payoff in period 1 from one experiment is given by $pA - I + 1$. In the second period, if the experiment is a success, unit E will continue to use the new design and unit F will copy it because the local condition in unit F is the same as in unit E, in such a case the payoff is $2A$. If the experiment is a failure, both units will use the old design with the payoff $2-R$. Hence the expected second period payoff is $p2A + (1-p)(2-R)$.

Let the experiment be carried out in unit M under the decentralized U-form. If the unit manager discovers that attribute 1 does not fit into local conditions, he makes adjustments on task x_m. But without coordinating with unit S, mis-matching in attribute 1 may occur. The expected first period payoff from one experiment is $(pA)(1-\rho')^2 - I + (1-\rho)^2$. With probability $p(1-\rho')^2$ the experiment is a success and in such a case the second period expected payoff is $2A(1-\rho)^2$. While with probability $1 - p(1-\rho')^2$ the experiment fails and in such a case the second period expected

[4] If local condition in product E and product F are stochastically independent, adjustment to local conditions in unit E is not the same as adjustment to local condition in unit F, therefore unit F, therefore unit F can't copy the result of the experiment carried out by unit E in the second period.

TABLE 1.

	MD	UD	Centralization
no experiment			
period 1	2	$2(1-\rho)^2$	$2\max\{\lambda^2,(1-\rho)^2\}$
period 2	2	$2(1-\rho)^2$	$2\max\{\lambda^2,(1-\rho)^2\}$
one experiment			
period 1	$pA-I+1$	$(pA)(1-\rho')^2-I+(1-\rho)^2$	$(pA)\max\{\lambda'^2,(1-\rho')2\}$ $-I+\max\{\lambda^2,(1-\rho)^2\}$
period 2	$p2A+(1-p)(2-R)$	$p(1-\rho')^2 2A(1-\rho)^2$ $+[1-p(1-\rho')^2]$ $(2(1-\rho)^2-R)$	$(p)\max\{\lambda'^2,(1-\rho')^2\}$ $(2A)\max\{\lambda^2,(1-\rho)^2\}$ $+[1-\max\{\lambda'^2,(1-\rho')^2\}p]$ $(2\max\{\lambda^2,(1-\rho)^2\}-R)$
two experiments			
one blueprint			
period 1	$2[pA-I]$	$2[(pA)(1-\rho')^2-I]$	$2[(pA)\max\{\lambda'^2,(1-\rho')^2\}-I]$
period 2	$p2A+(1-p)(2-2R)$	$p(1-\rho')^2 2A(1-\rho)^2$ $+[1-p(1-\rho')^2]$ $(2(1-\rho)^2-2R)$	$(p)\max\{\lambda'^2,(1-\rho')^2\}$ $(2A)\max\{\lambda^2,(1-\rho)^2\}$ $+[1-\max\{\lambda'^2,(1-\rho')^2\}p]$ $(2\max\{\lambda^2,(1-\rho)^2\}-2R)$
two blueprints			
period 1	$2[pA-I]$	$2[(pA)(1-\rho')^2-I]$	$2[(pA)\max\{\lambda'^2,(1-\rho')2\}-I]$
period 2	$(1-(1-p)^2)2A$ $+(1-p)^2(2-2R)$	$(1-(1-p)^2)(1-\rho')^2 2A(1-\rho)^2$ $+[1-(1-(1-p)^2)(1-\rho')^2]$ $(2(1-\rho)^2-2R)$	$(1-(1-p)^2)\max\{\lambda'^2,(1-\rho')^2\}$ $(2A)\max\{\lambda^2,(1-\rho)^2\}$ $+[1-(1-(1-p)^2)\max\{\lambda'^2,(1-\rho')^2\}]$ $(2\max\{\lambda^2,(1-\rho)^2\}-2R)$

payoff is $2(1-\rho)^2 - R$. The total expected second period payoff is therefore $p(1-\rho')^2 2A(1-\rho)^2 + [1-p(1-\rho')^2](2(1-\rho)^2 - R)$.

Under centralization, M-form and U-form are identical. If the unit manager finds that attribute does not fit into local conditions, he reports the problems to the center. The center receives two signals from each unit, one for attribute 1 and the other for attribute 2. The center then makes orders for adjustments. The expected first period payoff from one experiment is $(pA)\max\{\lambda'^2,(1-\rho')^2\} - I + \max\{\lambda^2,(1-\rho)^2\}$. With probability $\max\{\lambda'^2,(1-\rho')^2\}p$, the experiment is a success and in such a case the second period expected payoff is $(2A)\max\{\lambda^2,(1-\rho)^2\}$. While with probability $1-\max\{\lambda'^2,(1-\rho')^2\}p$ the experiment fails and in such a case the second period expected payoff is $2\max\{\lambda^2,(1-\rho)^2\} - R$. The total expected second period payoff is therefore $\max\{\lambda'^2,(1-\rho')^2\}p(2A)\max\{\lambda^2,(1-\rho)^2\} + [1-\max\{\lambda'^2,(1-\rho')^2\}p](2\max\{\lambda^2,(1-\rho)^2\} - R)$.

Consider the possibility of two experiments. There could be one blueprint or two independent blueprints. In the former case, because the local conditions in product E and product F are identical and there is only one blueprint, the second period expected payoff is the second period payoff with only one experiment less one reversal cost R if the experiment fails. Under the condition $pA < I$, two experiments with one blueprint is always dominated by one experiment in all organizational forms because the extra experiment only brings in costs without any benefits.

Now assume that two different and stochastically independent blueprints are given to managers. Because the two blueprints are different, E and F will make different adjustments even if they face identical local conditions. We note that the first period expected payoff will be the same as that in the case of only one blueprint. However, the probability of at least one revised blueprint being successful becomes $1-(1-p)^2$, which is higher than p. Therefore, the second period expected payoff will higher, replacing p by $1-(1-p)^2$. In each organizational form, using two independent blueprints always gives higher two period expected payoffs than using one blueprint.

The results of the above analysis are summarized in Table 1.

8. CONCLUSIONS

We have analyzed in this paper the comparative performances of two forms of economic organization: the U-form, where substitutable tasks are grouped together, and the M-form, where complementary tasks are grouped together. Using a team-theoretic framework, we compared the performance of these organizational forms in the coordination of routine activities and in their capacity to introduce innovations and carry out reforms.

Under attribute shocks and when there are gains from specialization, we found that U-form organizations perform better when coordination is centralized, whereas M-form organizations perform better when coordination is decentralized. Decentralized M-forms dominate centralized U-forms if the economic costs from the mismatching of attributes are high, if the quality of vertical information transmission inside the organization is relatively poor, if adjustments to predesigned production plans need to be made more frequently, and if gains from specialization are not too great. The converse holds for centralized U-forms. The effects of organizational forms with respect to the capacity for innovation and reform in an organization are more complicated depending on the nature of new ideas.

The presence of U-form versus M-form firms in different sectors of economic activity may thus be explained by the model. Moreover, business historians like Chandler, Williamson and others have documented the growth of the M-form of economic organization in the twentieth century. In the early part of the century, all large business firms were organized in U-forms. Accompanying the growth of these large firms, market demands became more sophisticated, more heterogeneous, and more volatile. The growth of the firms also depended more on innovations which, along with more sophisticated production, increased the demand for good communication. But communication quality is ultimately limited by a human being's capability to process information and understand its content. According to our model, the growing superiority of the M-form may be explained by the fact that technological progress has dramatically increased the costs of coordination failures in the form of mismatching of attributes, and that this tendency has grown faster than the increase in the quality of vertical information transmission and gains from specialization. As we see, quality of coordination is crucial for the performance of organizations.

Our analysis also carries over to the organizational forms in centrally planned economies. The choice of the centralized U-form by Soviet planners is generally explained by their desire to exploit the gains from specialization. Similarly, the choice of the M-form of economic organization in China was justified by the fear of losing vertical communication channels and experiencing damage from coordination failures in case of war. Interestingly, these initial choices of organizational forms have had an important effect on reform strategies. The decentralized M-form in China allowed for experimentation with reforms in a gradual and incremental way. This was less true for the former centrally planned economies of Central and Eastern Europe where specialization and centralization were stronger, leaving much less room for local experiments, and where a radical approach to reform was chosen.

APPENDIX

Proof of Proposition 2 We prove this proposition in two steps. We first show that the above decision rule maximizes the expected output of product i, then we show that it also maximizes the organizational payoffs.

The proof for the first part is standard: given the prior probability ρ's and conditional probability λ's, we calculate posterior probability of ε's conditional on signal (s_s^i, s_m^i). Then for each such signal, we obtain the optimal decision $d^i(s_s^i, s_m^i)$, which is given by the above expressions. Hence, by taking conditional expectations, we obtain

$$\begin{aligned} E\{x^i(d^i(s_s^i, s_m^i), \varepsilon_s^i, \varepsilon_m^i)\} &= E\{E[x^i(d^i(s_s^i, s_m^i))|s_s^i, s_m^i]\} \\ &\geq E\{E[x^i(d(s_s^i, s_m^i))|s_s^i, s_m^i]\} \\ &= E\{x^i(d(s_s^i, s_m^i), \varepsilon_s^i, \varepsilon_m^i))\}, \end{aligned}$$

for all $d(s_s^i, s_m^i)$. Hence the above expression gives the highest expected output i.

Next, for any non-decreasing function $f(x^E, x^F)$, and for all $\{d(s_s^E, s_m^E), d(s_s^F, s_m^F)\}$, we have:

$$\begin{aligned} & E\{f(x^E(d^E(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d^F(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\} \\ = \; & E\{Ef(x^E(d^E(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d^F(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\}|s_s^F, s_m^F, \varepsilon_s^F, \varepsilon_m^F\} \\ \geq \; & E\{Ef(x(d(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d^F(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\}|s_s^F, s_m^F, \varepsilon_s^F, \varepsilon_m^F\} \\ = \; & E\{f(x(d(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d^F(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\} \\ = \; & E\{Ef(x(d(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d^F(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\}|s_s^E, s_m^E, \varepsilon_s^E, \varepsilon_m^E\} \\ \geq \; & E\{Ef(x(d(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\}|s_s^E, s_m^E, \varepsilon_s^E, \varepsilon_m^E\} \\ = \; & E\{f(x^E(d(s_s^E, s_m^E), \varepsilon_s^E, \varepsilon_m^E), x^F(d(s_s^F, s_m^F), \varepsilon_s^F, \varepsilon_m^F)\}. \end{aligned}$$

Therefore, $\{d(s_s^E, s_m^E), d(s_s^F, s_m^F)\}$ is optimal. ▮

Proof of Lemma 1 (1) Under the decentralized M-form, when there is only one shock, the benefit of making one adjustment is $1-\alpha$ and the cost is c. When there are two shocks, the benefit of making two adjustment is $1-\alpha$ and the cost is $2c$.

(2) For $\lambda + \rho > 1$, define

$$\underline{c} = (\lambda + \rho - 1)/(\lambda\rho + (1-\lambda)(1-\rho)).$$

Because $\lambda(1-\rho) + \rho \leq 1$ (with equality only if $\lambda = 1$), $\underline{c} \leq 1$ (with equality only if $\lambda = 1$). Define $c_1 = \underline{c}/2$, and

$$c_2 = [\lambda(1-\rho)/(\lambda(1-\rho) + (1-\lambda)\rho)]\underline{c}.$$

We have $c_1 \leq 1/2$ and $c_2 \leq 1$. Also because $\rho \leq (1/2) \leq \lambda$, we have $1/2 \leq \lambda(1-\rho)/(\lambda(1-\rho) + (1-\lambda)\rho) \leq 1$. Therefore $c_1 \leq c_2$.

Suppose $s = (1,1)$ is observed. If $c > c_1$,

$$[\lambda\rho/(\lambda\rho + (1-\lambda)(1-\rho))]^2 - 2c < [(1-\lambda)(1-\rho)/(\lambda\rho + (1-\lambda)(1-\rho))]^2,$$

that is, $d = (0,0)$ is preferred to $d = (1,1)$. Furthermore,

$$\begin{aligned} & [\lambda\rho/(\lambda\rho + (1-\lambda)(1-\rho))][(1-\lambda)(1-\rho)/(\lambda\rho + (1-\lambda)(1-\rho))] - c \\ < \; & [(1-\lambda)(1-\rho)/(\lambda\rho + (1-\lambda)(1-\rho))]^2, \end{aligned}$$

that is, $d = (0,0)$ is preferred to $d = (1,0)$. Hence $d = (0,0)$ is optimal.

Similarly, if $c < c_1, d = (1,1)$ is preferred to $d = (0,0)$.

Suppose $s = (1,0)$ is observed, we can similarly show that $d = (1,0)$ if $c < c_2$ and $d = (0,0)$ if $c > c_2$. ▌

Proof of Lemma 2 (1) The optimal decision is bang-bang. The unit cost of transfer is k and the benefit is 1, therefore, the optimal decision is $t = 0$ if $k > 1$ and $t = \eta/2$ if $k < 1$. When $t = 0$, the probability of at least one shock is 4σ, and in such an event, the loss is η. Hence the expected payoff is $1 - 4\sigma\eta$. When $t = \eta/2$, a transfer occurs with probability 4σ and the payoff is $1 - \eta/2 - \eta/2k$. No transfer occurs with probability $1 - 4\sigma$ with payoff 1. Therefore the expected payoff is $1 - 2\sigma\eta(1 + k)$.

(2) Consider the strategy: {transfer $(0,0)$ if a shock is observed; transfer $(\eta/2, \eta/2)$ if no shock is observed}. Then

$$\max 4\sigma[1-\eta+t-2tk] + (1-4\sigma)[1-4tk] = \max 1 - 4\sigma\eta + 4\sigma t - 4tk(1-2\sigma)$$

subject to $t \le \eta/2$.

The first order condition gives:

if $k < \sigma/(1-2\sigma), t = \eta/2$;

if $k > \sigma/(1-2\sigma), t = 0$.

(3) Updating when s_1 is observed:

$P(r_1|s_1) = \mu\sigma/(\mu\sigma + \nu(1-\sigma))$;

$P(r_i|s_1) = \nu\sigma/(\mu\sigma + \nu(1-\sigma)), i = 2,3,4$; and

$P(r_5|s_1) = \nu(1-4\sigma)/(\mu\sigma + \nu(1-\sigma))$.

Similarly for s_2 to s_4. When s_5 is observed:

$P(r_i|s_5) = \nu\sigma/(4\nu\sigma + \mu(1-4\sigma)), i = 1,2,3,4$; and

$P(r_5|s_5) = \mu(1-4\sigma)/(4\nu\sigma + \mu(1-4\sigma))$.

The optimal decisions if s_1 is observed is derived from

$$\begin{aligned} & \max[\mu\sigma(1-\eta+t) + \nu\sigma(1-\eta-t) + 2\nu\sigma(1-\eta) + \nu(1-4\sigma)(1-t) \\ - \; & kt(\mu\sigma + \nu(1-\sigma))]/(\mu\sigma + \nu(1-\sigma)) \end{aligned}$$

subject to $t \le \eta/2$. The first order condition gives:

if $k < \underline{k}, t = \eta/2$;

if $k > \underline{k}, t = 0$.
Similarly for s_2 to s_4.
If s_5 is observed:

$$\max[\nu\sigma(1-\eta+t) + \nu\sigma(1-\eta-t) + 2\nu\sigma(1-\eta) + \mu(1-4\sigma)(1-t) - kt(4\nu\sigma + \mu(1-4\sigma))]/(4\sigma\nu + \mu(1-4\sigma))$$

subject to $t \leq \eta/2$. The first order condition gives:

$$-\mu(1-4\sigma) - k(4\nu\sigma + \mu(1-4\sigma)) < 0,$$

therefore always set $t = 0$.
If $k < \underline{k}$,

$$\begin{aligned} EX_C &= 4[(1-\eta/2)(\mu\sigma + \nu(1-4\sigma)) + 3\nu\sigma(1-7/6\eta) \\ &- k\eta(\mu\sigma + \nu(1-\sigma))/2] + 4\nu\sigma(1-\eta) + \mu(1-4\sigma) \\ &= 1 - (\eta/2)[(1-\mu) + (5-\mu)\sigma] - (k\eta/2)[4\mu\sigma + (1-\mu)(1-\sigma)]. \end{aligned}$$

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Proof of Proposition 8 (1) Applying Lemma 2:
(i) if $k > 1, EX_{UD} = EX_{MD} = 1 - 4\sigma\eta$ ($t = 0$ in both organizations);
(ii) if $\sigma/(1-2\sigma) < k < 1, EX_{UD} = 1 - 2\eta\sigma(1+k) > EX_{MD} = 1 - 4\sigma\eta$ ($t = \eta/2$ in U-form and $t = 0$ in M-form); if $0 < k < \sigma/(1-2\sigma), EX_{UD} = 1 - 2\eta\sigma(1+k) > EX_{MD} = 1 - 2\sigma\eta - 2k\eta(1-2\sigma)$ ($t = \eta/2$ in both organizations); and
(iii) if $k = 0, EX_{UD} = EX_{MD} = 1 - 2\sigma\eta$ ($t = 0$ in both organizations).
(2) (i) If $\mu = 1$,

$$EX_C = \begin{cases} 1 - 2\eta\sigma(1+k) & \text{if } k < 1 \\ 1 - 4\sigma\eta & \text{if } k > 1 \end{cases}$$

which is identical to EX_{UD}.
(ii) If $\mu < 1, EX_{UD} > EX_C > EX_{MD} = 1 - 4\sigma\eta$ when $\sigma/(1-2\sigma) < k < 1 - 2\nu(1-2\sigma)/(\mu\sigma + \nu(1-\sigma))$. If $\mu < 1$, as $k \to 0, EX_{MD} \to EX_{UD}$, but

$$EX_C \to 1 - (\eta/2)(1 - \mu + (5-\mu)\sigma) < 1 - 2\eta\sigma = EX_{UD}.$$

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