Coordinating Changes in M-form and U-form Organizations[1]

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Abstract

We model the coordination of specialized tasks inside an organization as "attribute matching." Using this method, we compare organizational forms (U-form and M-form) in coordinating changes. In our framework, organizational forms affect the information structure of an organization and thus the way to coordinate changes. Compared to the U-form, the M-form organization achieves better coordination but suffers from higher costs due to a lack of scale economies or a lack of what we call "attribute compatibility." The distinctive advantage of the M-form is experimentation, which gives the organization more flexibility leading to more innovation and reform. Our theory applies to business firms, transition economies, and the organization of government. For transition economies, our theory relates the initial conditions of organizational differences with reform strategies, especially the "big-bang" approach in Eastern Europe and the "experimental" approach in China.

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"Organizations are systems of coordinated action among individuals and groups."

March and Simon, *Organizations* (2nd edition), 1993

I. Introduction

Understanding how economic activity is coordinated inside organizations has always been one of the most fascinating questions in economics. Since Adam Smith, economists have recognized that the benefit of organizing large-scale production comes from coordinated specialization. When there is no specialization, all agents perform the same operations. There is then no need for coordination and no gain from having agents work together in one organization. However, when there is specialization, coordination becomes critical. Adam Smith and Chandler (1962) have described how different organizations coordinate specialized tasks.

Different organizational forms differ in their coordination capacity. What is the difference between coordinating innovation in a business firm run by specialized departments and in one run by self-contained profit centers? How do organizational forms inside government affect economic reform strategies in transition economies? What is the difference between coordinating changes in a unitary (centralized) state with specialized ministries and in a federal state with coordinating powers delegated to regions?

To answer these questions, we introduce the concept of task coordination inside an organization as matching the attributes of specialized tasks in a stochastic environment. This concept is inspired by Milgrom and Roberts' (1990, 1992) discussion of "design attributes" in their studies of organization of firms. We view coordination as assembling complementary parts, such as the assembling of subroutines for a software package; synchronizing travel plans and accommodating logistics for a conference; reforming an economy by restructuring enterprises and establishing corresponding social safety-net, etc. Each complementary part is characterized by its attributes: time, location, technical specifications (such as size, weight, and bits), legal and administrative terms, etc. A product or a service is completed successfully only if the characteristics of each attribute of the various parts are matched. To take a simple example, the diameter of a screw must match that of a bolt so that they both meet certain standards of material resistance. They must be transported to a given location at a given time. Most products and services require a much more sophisticated assembling of parts, each part having numerous attributes which are relevant in this matching process. Failure in the matching of attributes often implies a breakdown. For example, the engine of a Rolls Royce car cannot fit into the body of a mini-Morris; a conference can be a disaster if room allocation conflicts with other academic programs. Note that our concept of coordination differs from the one arising with multiple equilibria in games.

In a world without uncertainty, as long as an organization has a perfect plan in which all the attributes are matched by design, all the tasks can be implemented without a problem. Alternatively, as long as all agents are able to communicate perfectly (no mistakes, no cost, no time delay), matching attributes will not be a problem either even when there is uncertainty. However, when there are exogenous random shocks which we will call "attribute shocks" and when communication between agents is imperfect, the coordination problem becomes non-trivial and having a perfect plan alone is insufficient. This is because when there is a shock affecting an attribute of one task, any change of this attribute will affect its matching with attributes of other tasks. Thus, the corresponding attributes of other tasks must be adjusted to make them match. But the quality of the adjustment of attributes depends itself on the quality of communication inside an organization. The communication problem arises because only a manager directly and frequently engaging in a particular task has first-hand information and knowledge about that task. Communication is necessary for others to use such information and knowledge, but communication is likely to be imperfect because message transmission, due to technical bugs as well as human misunderstanding, can go wrong. Hayek's (1945) famous notion of "local information," the information about particular location and circumstance, fits well our framework -- direct involvement in a task gives rise to good knowledge about that task. The communication problems we consider are more general and they not necessarily related to geographic distance. They arise whenever the absence of direct involvement in a task implies poorer knowledge about it. For convenience, we often refer to a manager as "local manager" and the knowledge he possesses as "local information." But the term "local" used here does not necessarily carry a geographical meaning.

It is important to note that the communication problem is endogenous, depending on how tasks and decision-making power are assigned within an organization. That is, the organizational form matters. We define an M-form (multi-divisional form) organization as one that consists of self-contained units where complementary tasks are grouped together. In contrast, a U-form (unitary form) organization is decomposed into specialized units where similar tasks are grouped together. These units are not self-contained in terms of final output. Because the M-form and the U-form organizations assign tasks differently, the communication problems they face are different.

In order to focus on the coordination problem, we assume away the incentive problem and take the team theoretical approach. Elsewhere, Maskin, Qian, and Xu (1999) provide an analysis of incentive problems in M-form and U-form organizations in a similar setup. They have demonstrated that different organizational forms give rise to different information about managers' performance and therefore differ according to how incentives encourage good performance. In particular, they have shown that the M-form may provide better incentives than the U-form because it promotes yardstick competition, that is, relative performance evaluation, more effectively. In this paper, we assume that managers under either organizational form have the same incentives to pursue the goal of economic efficiency. That is, there is no intrinsic advantage of one organizational form over another from the point of view of incentives. Therefore, all of our results are driven by coordination considerations.

In our setup, a simple trade-off emerges between better local coordination and a lack of scale economies in the M-form compared to the U-form. This is because units in the M-form are self-contained; local managers who have better information can do attribute matching, whereas in the U-form the attribute matching is done by top managers who rely on imperfect information transmitted by local managers. On the other hand, by having self-contained units in the M-form, one loses scale economies since similar tasks are organized in different units. By grouping similar tasks together in specialized units the U-form reduces the setup costs of changes. When both the communication quality and setup costs (and thus economies of scale) are high, the U-form dominates the M-form; otherwise the M-form dominates the U-form.

The main result delivered by the model is that the M-form is more flexible than the U-form in two aspects. First, it gives an option of local experimentation when innovation or reform has an uncertain outcome. Indeed, self-contained units make it beneficial to experiment with a new program locally before implementing it in the entire organization. This reduces the cost of learning about the quality of the program. In contrast, in the U-form, these benefits from experimentation cannot be reaped because of the complications in coordinating partial experiments across specialized units. Second, the M-form allows for parallel experimentation, yielding faster success in innovation or reform. The flexibility of the M-form can lead to a higher propensity to change, an important dynamic advantage compared to the U-form.

We extend the analysis by introducing another dimension of the coordination problem, that of "attribute compatibility." Attribute compatibility is a characteristic related to similar tasks and products. Whereas attribute matching refers to complementary tasks such as manufacturing and sales of cars, compatibility refers to serving different types of cars. Cars have a better compatibility if different types share common services or parts. When coordination for attribute compatibility between similar tasks is also needed, the M-form may suffer from coordination problems due to imperfect communication between the local managers and the top manager, since in the M-form similar tasks are performed in different units. Then the comparison between the M-form and the U-form is focused on the tradeoff between two types of coordination: attribute compatibility and attribute matching. When standardization in markets is more prepared to solve most of the compatibility problems, the M-form will still have more advantages than the U-form.

Our paper is, to our knowledge, the first to formalize coordination inside an organization as attribute matching. Milgrom and Roberts (1990, 1992) introduced the notion of "design attributes" to study the form of communication (prices or planned attributes) that should be used to coordinate a given decision. They find that non-price communication is optimal when errors of "fit" are very costly and the number of alternative possible designs that fit well is large. While Milgrom and Roberts focus on the form of communication, we study the effects of alternative management structures when the need for attribute matching is pervasive and compare explicitly how the M-form and the U-form organizations affect communication channels and thus coordination.[2]

While mainly providing a new theoretical and conceptual framework, our paper also gives applications to the three areas of business firms, transition economies, and the organization of government. First, our theory is relevant to the study of business firms. Becker and Murphy (1992) have emphasized that coordination costs limit the extent of specialization in organizations but have not compared the coordination capacity of various organizational forms. Chandler (1962, 1977) studied how the M-form corporation emerged and how it replaced the U-form to become the prevailing corporate form of large businesses in U.S. business history. Williamson (1975, 1985) theorized Chandler's works with two major focuses: the holdup problem and the overload problem of corporate headquarters. The holdup problem concerns how organizational forms affect incentives and contractual relationships within an organization.[3] With respect to the coordination problem, Williamson emphasized that M-form firms were more efficient than U-form firms because daily operations were decentralized to divisions, which reduced work overload at the corporate headquarters and freed their time for strategic planning.[4] However, if overload is the only problem, putting more staff and resources in the headquarters and in functional departments should reduce the problem, and there is no need to undergo a reorganization process. Chandler (1962, 1977) documents that this is not the case. Our theory is consistent with Chandler's cases showing how the design of communication channels within an organization has fundamental effects on coordination.

Our theory is also applied to transition economies. There is a striking difference between the

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[2] Related works include the team theoretical studies of organization and the management science literature. The team theory literature includes, among others, Marschak and Radner (1972) on the economic theory of teams, Weitzman (1974) on coordination using price and quantity, Crémer (1980) and Aoki (1986) on the optimal partition of workshops inside an organization, and Bolton and Dewatripont (1994) on the firm as a communication network. The related management science literature distinguishes between product-focused and process-focused corporations, and treats them as the result of minimization of coordination costs in unstable environments (Henderson and Clark, 1990, Hayes, Wheelwright, Clark, 1988, Stinchcombe, 1990, Athey and Schmutzler, 1994). These models, however, are not based on the notion of coordination as attribute matching.

[3] A large literature has been generated after Williamson, such as Grossman and Hart (1986) and Hart and Moore (1990).

[4] Aghion and Tirole (1995) analyzed how M-form and U-form organizations generate and solve the overload problem.

organization of the Soviet planning administration on one hand, and that of the Chinese planning administration, on the other hand (Qian and Xu, 1993). The Soviet economy was organized into many specialized or functional ministries (e.g., mining, machinery, textile, etc.), each controlling gigantic factories. This corresponds to a U-form organization (also known as a "branch organization"). In contrast, the Chinese economy has been organized mainly on a geographical principle (provinces, prefectures, counties, townships and villages). This corresponds to an M-form organization (also known as a "regional organization"). The M-form structure provides flexibility and allows for regional experiments without interfering with the rest of the economy, and thus can optimally induce an experimental approach. The difficulties in coordination prevent the U-form from exploiting this strategy. In the latter, reforms must be more comprehensive in order to avoid coordination failure and must be coordinated from the top. Therefore, our theory sheds light on the contrast between the observed "big-bang" approach in Eastern Europe and the former Soviet Union and the "experimental" approach in China (McMillan and Naughton, 1992; Dewatripont and Roland, 1997; Sachs and Woo, 1997). Moreover, our framework sheds new light on the troubles that Russian transition are currently facing. The U-form organization of the Soviet economy led to an extreme industrial concentration. Given that regions are not self-contained the devolution of authority to regional governments under Yeltsin in Russia after 1992 represents a shift from a U-form to a "collapsed" U-form, which is equivalent to a U-form where the communication between local and central authorities has completely broken down.

Finally, our theory is useful in understanding the organization of government, specifically, the comparison between the unitary and federal state. The unitary state can be viewed as a U-form organization and federalism as an M-form. The organization of the French and Japanese governments are examples of the former and that of the United States is the prominent example of the latter. The French and Japanese government organizations are much more centralized in Paris and Tokyo respectively, with specialized ministries having large powers and regional governments having little. Major changes in government programs, such as education and banking reforms, require initialization by the responsible ministries and coordination by the central government. In contrast, American federalism is known as a "laboratory of the states," in the famous words of the American Supreme Court Justice Louis Brandeis written in 1932. Indeed, many government policy changes in the U.S. were experimented by some states and the successful results were later imitated by others. The contrast between the unitary and federal states fits well our analysis of organizational forms.

The rest of the paper is organized as follows. Section II introduces the modelling of task coordination as "attribute matching." Section III explores the basic thesis on the advantage of the M-form in carrying out experimentation. Section IV extends the model to include the possibility of parallel experimentation when more than one blueprint is available at a given time. Section V incorporates coordination on attribute compatibility. Section VI discusses applications. Section VII concludes. The Appendix contains the proofs of the propositions.

II. Modelling Task Coordination as "Attribute Matching"

Consider an economy with two products (or regions), "A" and "B," and two processes (or functions), "1" and "2." The technology of the economy can be fully described by four tasks: 1A, 2A, 1B, and 2B, where task ir involves process i for product r. With this specification, we assume that the two products (or regions) are symmetric in the sense that each product (or region) has two processes (or functions).

We suppose that an innovation program is designed so that all attributes are matched perfectly *ex ante* in the blueprints. However, in implementing a program, there are always "attribute shocks" which are unexpected contingencies not taken care of in the blueprints. At the implementation stage of an innovation program, attributes of parts must be mutually adjusted to observed attribute shocks. We assume that attribute matching must take place between tasks 1r and 2r (r = A, B). In sections III and IV, we assume that no attribute matching is needed between the tasks across products and in section V, we extend the model by incorporating the requirement for attribute compatibility across products.

Our model has an infinite horizon with discount factor δ. We first assume that one and only one blueprint for change is available in each period to the top management of the organization. Later we allow the possibility of two independent blueprints in each period. With probability p the blueprint is a good one and with probability 1-p it is bad. Blueprints available over time are stochastically independent. We assume that if a blueprint is known to be good, then it will be good in the same unit (region) in the future and good in another unit (region). In contrast, good coordination (i.e., attribute matching) in one unit (region) cannot be "copied" in another unit (region), because of differences in local conditions. Therefore, if a blueprint tried in one unit (region) is found to be good and coordination has been successful, then the same blueprint can be used successfully elsewhere, but coordination is still necessary in order to adjust to local conditions before a successful outcome can be achieved.

In each period, a manager collects information about the attribute shocks. We assume that the manager of a unit has a perfect "local" information about his unit.[5] If required, the manager in one unit sends a message to another manager. Each message contains information about all the attributes in one task. We assume that information transmission across units is imperfect and the probability of each message being correct is λ with $0 \leq \lambda \leq 1$. This is because when managers are in different specialized units, they have different idiosyncratic knowledge and different interpretations of the same message. They may speak different languages; for example, engineering language differs from marketing language and the language of economists may differ from that of sociologists. Moreover, their communication may be restricted to short messages (such as messages carried by phone calls, faxes, memos, meetings, etc.), which may be subject to ambiguous interpretations. We assume that noises in information transmission are independent across tasks as well as over time. Based on the information received, the manager carries out his main job: attribute matching.

Consider the payoffs for unit A (payoffs for unit B are defined symmetrically). Let the status quo (without change) payoff in unit A. The benefits from change are defined as follows. Suppose the program is good, then (i) with change in task 1A but not in task 2A (or change in task 2A but not in task 1A), the

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[5] Assuming perfect local information within a unit makes the model simple. As long as the manager has a better "local" information our result will not be changed qualitatively. A manager has a better "local" information reflects the reality that even when there are several managers involved in one unit they share local information and communicate extensively with each other with a common language which reduces misunderstandings.

payoff is (R+1)/4 if the attributes between 1A and 2A are matched, otherwise 0; and (ii) with changes in both tasks 1A and 2A, the payoff is R/2 if the attributes between 1A and 2A are matched, otherwise 0. If the program is bad, then the payoff is always 0 when change is implemented.

Assumption 1. $pR > 1$: the expected per-period benefit from change is larger than the status quo.

We assume that all blueprints are made available for free, but for each manager there is a setup cost C associated with coordinating changes. This cost can be interpreted as a training cost, that is, to implement a program for change the managers need to be trained on how to match attributes of the program. Because blueprints are free and the setup costs for coordination are not, when a failure occurs in the previous period (either due to a bad program or bad coordination), the organization always prefers to use a new blueprint in the next period rather than retry the old one.

Assumption 2. $R/2(1-\delta) - C > 1/2(1-\delta)$, that is, the net benefit from change is better than the status quo for $p = 1$.

We now define U-form and M-form organizations. A U-form organization is set up along "functional lines." Two middle managers i (i = 1, 2) are responsible for collecting information about shocks in tasks iA and iB. Because the two tasks that need attribute matching are not assigned to the same middle manager, the two middle managers have to report the information to the top manager, who, after receiving information from the two managers, matches attributes between tasks 1r and 2r (r = A, B). This type of organization can be represented by Figure 1:

Figure 1: A U-Form Organization

Top Manager

Manager 1 Manager 2

Task 1A Task 1B Task 2A Task 2B

An M-form organization is set up along "product lines." The middle manager r (r = A, B) is responsible for collecting information about shocks in tasks 1r and 2r. Because the two tasks which require attribute matching are assigned to the same manager, the middle managers can match attributes between tasks 1r and 2r locally by themselves. The top manager provides a blueprint for change (and in section V, the top manager also coordinates attribute compatibility). This type of organization can be represented by Figure 2:

Figure 2: An M-Form Organization

Top Manager

Manager A Manager B

Task 1A Task 2A Task 1B Task 2B

Under the M-form, setup costs must be incurred in each unit since attribute matching is done separately in each product unit. This leads to higher setup costs. For example, both managers need to be trained to coordinate the changes. In contrast, under the U-form, only the top manager matches attributes in a centralized way. Therefore, the setup cost is correspondingly smaller.[6] For simplicity, we will assume that only one setup cost is required when only one manager coordinates.

We provide two examples below to illustrate our concept of coordination inside an organization as attribute matching.

Example 1. Coordinating innovations: manufacturing trucks

Suppose there are two functions to produce trucks. Function 1 consists in supplying many types of bearings to the truck industry, and function 2 consists in manufacturing trucks. Because of differences in local road conditions, each region has its idiosyncratic preference for truck models (call them model A and model B trucks respectively). Task 1r is to produce bearings for a model r truck, and task 2r is to produce model r trucks for region r, where r = A and B.

The attributes of bearings and truck models should be matched to each other in order to produce quality trucks. For example, the bearings should match the transmission equipment of the truck. If some attributes between the bearings and the truck are not matched, the truck cannot be made. Coordination consists in finding a solution to match bearings with parts of trucks. A technological innovation in transmission may make a truck more efficient, but it will change the technical requirements for bearings.

Suppose there is an innovation in the transmission system and the innovation outcome is uncertain. In the case where a new transmission system is good and every set of bearings is matched with every part of a truck, the new truck will be better than the old one. However, if one of the bearings does not fit with the corresponding part of the truck, the new truck will not work.

The firm can be organized into specialized units, a machine-building unit and a unit for producing

[6] We note that in this framework, the M-form has an option to "mimic" the U-form by requiring regional managers to send messages to the top for coordination, but the U-form cannot "mimic" the M-form. However, when coordination on compatibility is added into the model in section V, the two organizational forms will look symmetric.

bearings, with centralized matching of the attributes between bearings and trucks (U-form). It can also be organized along product lines, where each product unit is responsible for producing one truck model (the M-form).

Example 2. Coordinating reforms: enterprise restructuring and creation of a social safety net

Suppose an economic reform consists of two components: enterprise restructuring (laying off excess workers) and creation of a social safety net. Task 1r is layoffs in region r and task 2r is paying unemployment benefits through the social safety net in region r, where r = A and B.

The attributes of enterprise restructuring are the number and individual characteristics of the laid-off workers, such as age, seniority, family composition, length of residence, sex, type of contract, current wage, history of employment, etc. The attributes of compensation from the social safety net are rules of eligibility, such as length of employment, special circumstances (veteran or not), status of enterprises, rules of benefits such as size and length, types of benefits (monetary or not), technical support of computers, administration, budget, etc. If some attributes of the two tasks are not matched, some laid-off workers may not be compensated appropriately.

If the reform is organized by specialized ministries (or committees), then each ministry is responsible for either enterprise restructuring or the social safety net, and the national government is responsible for matching the attributes between enterprise restructuring and the social safety net (the U-form). It is possible that there will be bad coordination between layoff policies and the creation of the social safety net, leading to riots. For example, the rules for eligibility set at the national level may be completely inappropriate in some important regions which have a concentration of older workers, if the national rule for pension eligibility does not make workers close to pension age eligible for any benefits.

If the reform is organized by the regions, each regional government is responsible for matching the attributes between enterprise restructuring and the social safety net in its own region (the M-form). Under this type of organization, layoff policies and the institution of social safety nets can be better coordinated within each region so that riots can be prevented.

III. Coordination, Experimentation, and Organizational Flexibility

In this section, we compare the M-form and the U-form assuming that only one blueprint is available in each time period. Under both organizational forms, the payoff from the status quo (i.e., no reform) is 1 for each period, and thus the status quo discounted payoff is $1/(1-\delta)$.

Consider first the situation in which an organization starts a reform in both of its units and continues in that way afterwards. Under the M-form, every unit manager will be responsible for matching the attributes of the two tasks within his unit. With perfect local information, attribute matching under the M-form will be performed perfectly. If a program is good, which happens with probability p, the total payoff from the two units is $R/(1-\delta)$. If a program is bad, which happens with probability 1-p, the current payoff is zero, and a new program will be tried in the next period. Therefore, the expected payoff of continued reform in an M-form is

$$\pi_{m2} = pR/(1-\delta) + (1-p)\delta\pi_{m2},$$

from which we obtain

$$\pi_{m2} = pR/\{(1-\delta)[1-(1-p)\delta]\}.$$

On the cost side, in period 1, 2C is paid because two managers are involved in coordination. With probability p, the program is good so no more costs need to be paid afterwards. But with a probability 1-p the program is bad, which is discovered after one period of change. Then a new program is tried in the next period. Because the managers need to be retrained for matching attributes, an additional cost of 2C is paid in the next period, and so on. Therefore, we should have

$$c_{m2} = 2C + \delta(1-p)c_{m2},$$

from which we derive

$$c_{m2} = 2C/[1-(1-p)\delta].$$

Under the U-form, the top manager is responsible for coordinating the four tasks. He thus receives four messages through noisy communication, each corresponding to one of the four tasks. When the program is bad (with probability 1-p), the innovation fails, and a new program will be tried in the next period. If the program is good (with probability p), there are three possibilities: (i) With probability λ^4, coordination is successful for both products A and B. (ii) With probability $(1-\lambda^2)^2$, coordination fails in both A and B. This will give the same outcome as a bad program. (iii) With probability $2\lambda^2(1-\lambda^2)$, coordination for one of the two products is successful. In this case, knowing that the program is good, the top manager will use the same program for the product for which the coordination failed and solve only the attribute matching problem in the next period. Hence, the payoff of reform under the U-form is

$$\pi_{u2} = p\{\lambda^4 R/(1-\delta) + 2\lambda^2(1-\lambda^2)[R/[2(1-\delta)] + \delta\pi] + (1-\lambda^2)^2\delta\pi_{u2}\} + (1-p)\delta\pi_{u2},$$

where π is the expected payoff of change for one product for a good program:

$$\pi = \lambda^2 R/[2(1-\delta)] + (1-\lambda^2)\delta\pi,$$

which implies that

$$\pi = \lambda^2 R/\{2(1-\delta)[1-(1-\lambda^2)\delta]\}.$$

Using the above recursive formula of π, we obtain

$$\pi_{u2} = p\{2\lambda^2[\lambda^2 R/2(1-\delta) + (1-\lambda^2)R/2(1-\delta) + (1-\lambda^2)\delta\pi + (1-\lambda^2)\delta\pi - (1-\lambda^2)\delta\pi]/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}$$

$$= 2p[\lambda^2 R/2(1-\delta) + \lambda^2(1-\lambda^2)\delta\pi + (1-\lambda^2)\delta\pi - (1-\lambda^2)\delta\pi]/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}$$

$$= 2p\pi[1 - (1-\lambda^2)^2\delta]/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}$$

$$= \lambda^2 pR[1-(1-\lambda^2)^2\delta]/\{(1-\delta)[1-(1-\lambda^2)\delta][1-\delta[p(1-\lambda^2)^2+(1-p)]]\}.$$

On the cost side, when an innovation is introduced in period 1, only a setup cost C is paid (instead of 2C in the M-form) because only the top manager matches attribute. With probability 1-p the program is bad, which is discovered after one period. With probability $p(1-\lambda^2)^2$ the program is good but coordination fails for both products. In both cases, a new program is tried in the next period. When the program is good and coordination is successful for at least one of the two products, the program will be known to be good. In such a case, no new setup cost needs to be paid in the next period. Indeed, the top manager has already been trained for that program and he has been able to successfully coordinate attribute matching for one product. Under this assumption, we have:

$$c_{u2} = C + \delta[p(1-\lambda^2)^2 + (1-p)]c_{u2},$$

from which we obtain

$$c_{u2} = C/\{1-[p(1-\lambda^2)^2+1-p]\delta\}.$$

Lemma 1: (1) $\pi_{u2} \leq \pi_{m2}$, and π_{u2} increases in λ and reaches π_{m2} at $\lambda = 1$.

(2) c_{u2} decreases in λ, and $c_{u2} < c_{m2}$ if and only if $\delta(1\text{-}p+2p(1\text{-}\lambda^2)^2) < 1$.

When communication between the middle managers and the top manager is perfect, the two organizational forms are equivalent in the expected payoffs. However, when communication is not perfect and because there is no communication problem under the M-form, the M-form always has a higher expected benefit than the U-form. Under the U-form, costs decrease with λ because better communication decreases the probability of failure with change, thereby lowering the probability of drawing new experiments and incurring repeated setup costs. The trade-off between costs under the M-form and the U-form is also related to the quality of communication under the U-form. The latter avoids the costs of duplication but bad communication leads to a higher failure rate, possibly leading to higher total costs because of the need to draw more experiments before achieving success.

We define the expected net payoff under the M-form and U-form, respectively,

$$M_2 = \pi_{m2} - c_{m2},$$

and

$$U_2 = \pi_{u2} - c_{u2}.$$

Proposition 1: Comparing the M-form and the U-form:

(1) the M-form has a higher expected net benefit than the U-form if communication quality (λ) is low enough: for p and C given, there exists $\lambda_{mu} \in (0,1)$ for which $M_2 > U_2$ if and only if $\lambda < \lambda_{mu}$.

(2) the U-form has a higher expected net benefit than the M-form if the setup cost C is high enough: when $c_{u2} < c_{m2}$ and for p and λ given, there exists $C_{mu} > 0$ such that $U_2 > M_2$ and if only if $C > C_{mu}$.

Proposition 1 formulates the basic tradeoff between coordination and scale economies in implementing changes under the M-form and the U-form. The U-form has an advantage in scale economies because the top manager is responsible for coordination in the entire organization. The organization thus saves on setup costs but the U-form has disadvantages in coordination because local information is communicated imperfectly from the local managers to the top manager. In contrast, the M-form has better coordination because managers can make better use of local information for coordination purposes, but it suffers from disadvantages in scale economies: it pays twice the setup costs because two local managers are responsible for attribute matching instead of one top manager.[7] In view of this trade-off, the M-form will be more efficient than the U-form when communication quality is relatively low, or when the setup cost is relatively small.

We next introduce the possibility that an organization starts a program for change in one of its two units and later extends it to another unit, conditional on successful implementation in the first unit. In other words, we look at the possibility of experimentation in implementing changes.

Under the M-form, suppose at first that a program is introduced in unit A whereas the status quo is maintained in unit B. If the program is a good one, the first period payoff is (R+1)/2. In the second period, the same program is then used in unit B. From then on, the payoff is always R per period. However, if the program is bad, the experimenting unit A will get 0 payoff and the non-experimenting unit B will get 1/2. In this case, a new experiment in unit A will take place again in the next period. Therefore, the expected payoff of the M-form with experimentation in one unit is given by

$$\pi_{m1} = p\{R/2(1-\delta) + 1/2 + \delta R/2(1-\delta)\} + (1-p)\{1/2 + \delta\pi_{m1}\},$$

that is,

$$\pi_{m1} = p[R+(1-\delta)+\delta R]/2(1-\delta) + (1-p)\{1/2+\delta\pi_{m1}\}.$$

Therefore, we obtain

$$\pi_{m1} = [pR(1+\delta)+(1-\delta)]/\{2(1-\delta)[1-(1-p)\delta]\}.$$

The setup cost in the first period is C because only unit A's manager does attribute matching. If the program is good, unit B will use the same program in period 2 and another cost C will be paid in period

[7] In Bolton and Farrell (1990) it is coordination failure (in the context of multiple equilibria) that creates duplication costs. In our model, coordination is defined as attribute matching inside an organization while the duplication of setup costs is related to the lack of scale economies or specialization (on the latter point, see also Becker and Murphy (1992)). Here, there is no causality between coordination failure and the duplication of setup costs.

2 because unit B's manager needs to match attributes according to local conditions. Unit B thus imitates unit A's success, but does not copy it, since local coordination is still required to introduce the successful blueprint. With probability 1-p, the program is bad and a new blueprint must be tried. We are then back to the situation of period 1. Hence we get,

$$c_{m1} = C + \delta[pC + (1-p)c_{m1}],$$

which implies that

$$c_{m1} = (1+p\delta)C/[1-(1-p)\delta].$$

We define the net expected payoff under the M-form with an experimentation strategy as

$$M_1 = \pi_{m1} - c_{m1}.$$

Because of Assumption 1, $pR > 1$, we have:

Lemma 2: (1) $\pi_{m1} < \pi_{m2}$, and $c_{m1} < c_{m2}$.

(2) $dM_2/dp > dM_1/dp > 0$.

Both the expected net benefits under M_1 and M_2 monotonically increase with p. By Lemma 2, we can define p_{m2}^* as the probability such that $M_2 = 1/(1-\delta)$ and p_{m1}^* as the probability such that $M_1 = 1/(1-\delta)$, where $1/(1-\delta)$ is the status quo payoff. Then, for all $p > p_{m1}^*$, M_1 has higher expected net payment than the status quo; and for all $p > p_{m2}^*$, M_2 has higher expected net payment than the status quo. Let $\underline{p}$ be the probability such that $M_1 = M_2$. The following proposition compares two strategies in the M-form: "experimentation" and "immediate full change" (i.e., change introduced in both units simultaneously).

Proposition 2: (1) $p_{m1}^* < p_{m2}^* < \underline{p} < 1$. That is, $M_1 > M_2$ if and only if the uncertainty $p < \underline{p}$, and experimentation dominates the status quo while immediate full change does not for $p \in (p_{m1}^*, p_{m2}^*)$.

(2) for p given, experimentation yields a higher expected net benefit if and only if setup cost $C > C_{12} = (pR-1)/2(1-p\delta)$.

Proposition 2 demonstrates the following tradeoff. Experimentation provides an option value of waiting to learn about the quality of the blueprint before implementing the full program for change, but it comes at the cost of delaying a successful full change in the whole organization. The difference in the expected net benefits between experimentation and immediate full change under the M-form is given by

$$M_1 - M_2 = \{C(1-p\delta)-(pR-1)/2\}/[1-\delta(1-p)].$$

The first term $C(1-p\delta)$ in the numerator indicates the option value of waiting to learn about p before sinking C in an additional unit. This option value of waiting increases as p decreases, i.e. when there is greater uncertainty about the value of the blueprint. Therefore, experimentation can save on setup costs because of the option value of early reversal of a bad blueprint (Dewatripont and Roland, 1995). The second term in the numerator $(pR-1)/2$ (which is positive by Assumption 1) shows the cost of delaying experimentation in one unit under M_1. This cost increases with p. Clearly, when $p = 1$, $M_2 > M_1$ since the numerator becomes $C(1-\delta)-(R-1)/2$, which is smaller than zero by Assumption 2. M_2 continues to dominate M_1 until p falls below $\underline{p}$. In particular, when p falls further into the region of $[p_{m1}^*, p_{m2}^*]$, M_1 is greater than the status quo but M_2 is not.

We now analyze the possibility of experimentation under the U-form. Without loss of generality, we assume that at first a blueprint is implemented in unit 1 whereas unit 2 maintains the status quo. In line with our assumptions, the top manager does the attribute matching for products A and B.

We assume that the quality of the program (good or bad) can be discovered even when the change is implemented for only one task. We further assume that in order to match attributes of two tasks, whenever there is a change in at least one task, information (and thus communication) about the attributes of both tasks is needed. This is because even if a change is introduced in one task, attribute matching always involves another task. Therefore, under U-form with change in only one unit, all messages corresponding to the four tasks must be communicated by the two middle managers to the top manager.

After one period of experimentation in one unit, if a program is bad, the innovation fails, and in the next period a new program will be tried. If a program is good, there are three possible outcomes: (i) With probability λ^4 attribute matching is achieved for both products A and B. Then in the next period, the same program is used in both units and the final payoff will only depend on the outcome of attribute matching. (ii) With probability $(1-\lambda^2)^2$, coordination is bad for both A and B. This will give the same outcome as a bad program and a new program will be tried in the next period. (iii) With probability $2\lambda^2(1-\lambda^2)$, coordination for A or B is successful which will reveal that the program is good. In the next period, the two units will use the same program and the payoff for the earlier failed product will depend on the outcome of attribute matching. Hence, the expected payoff of the U-form with experimentation is

$$\pi_{u1} = p\{\lambda^4[(R+1)/2 + \delta 2\pi] + 2\lambda^2(1-\lambda^2)[(R+1)/4 + \delta 2\pi] + (1-\lambda^2)^2\delta\pi_{u1}\} + (1-p)\delta\pi_{u1},$$

where π is, as above, the expected payoff of reform in one region when the program is good, as defined above. Hence, we obtain

$$\pi_{u1} = p\{\lambda^4[(R+1)/2 + \delta 2\pi] + 2\lambda^2(1-\lambda^2)[(R+1)/4 + \delta 2\pi]\}/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}.$$

Under the U-form, the setup cost is the same as reform without experimentation. This is because coordination is done at the top and always requires four messages to be sent to the top manager who must be trained to do the appropriate coordination. We also assume that the setup cost C enables the manager to implement both partial and full change.[8] Therefore,

$$c_{u1} = c_{u2} = C/\{1-[p(1-\lambda^2)^2+1-p]\delta\}.$$

We define the net expected payoff under a U-form with experimentation as

$$U_1 = \pi_{u1} - c_{u1}.$$

<u>Proposition 3:</u> Under the U-form, experimentation is always dominated by immediate full change:

$$\pi_{u1} < \pi_{u2},\ c_{u1} = c_{u2}, \text{ and } U_1 < U_2.$$

The U-form organization does not benefit from experimentation because of the complications involved in coordinating activities. While the setup cost is not lower as with full change, there is no additional benefit in coordination and there are only costs in delaying expected benefits.

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[8] It would be reasonable to assume that the setup cost should be incurred twice, a first time when partial innovation is tried and a second time when the full innovation is implemented since the nature of the coordination is different in both cases. This assumption would only reinforce the result of Proposition 3.

Since partial innovation in the U-form never occurs in equilibrium, it is useful to give an example. Think of changes in computer software where task 1 represents change in the operating system and task 2 change in a word processor. Experimentation under U-form in this case means, for example, first changing the operating system (from DOS to windows 95), and then changing the word processor (from WordPerfect 5.1 to WordPerfect 8). In this example, partial innovation involves first matching the attributes of the old word processor with the new operating system (via a solution like the "DOS prompt") and then matching the attributes of the new operating system with the new word processor. In terms of difficulty of coordination, one gains nothing from this partial innovation and one might just as well directly introduce both changes. This is the message of Proposition 3.

The flexibility of the M-form yields an advantage over the U-form:

Proposition 4: (1) the U-form has higher expected net benefits than the M-form if the quality of communication λ is close enough to 1.

(2) Experimentation under the M-form yields higher expected net benefits than immediate full change under either M-form or U-form if the quality of communication λ is small enough and either $p < \underline{p}$ or $C > C_{12} = (pA-1)/2(1-p\delta)$.

When communication quality is high, the U-form will dominate because of its advantages in scale economies. The more interesting results are those on the flexibility of the M-form. From Propositions 2 and 3 we know that when the probability of success is low or the setup cost is high, the M-form has the option of experimentation while experimentation has no value to the U-form. In such a case, the M-form can do better than the U-form, provided communication quality is low enough.

IV. Coordination and Parallel Experimentation

In this section we assume that two independent blueprints are available at a given time. This introduces a possibility that both blueprints are tried simultaneously in two units in the M-form. If there is one successful experiment in one unit, it can be copied costlessly in the other unit, as in the previous section. Under this strategy, benefits

$$\pi_{m11} = p^2R/(1-\delta) + 2(1-p)p\{R/2(1-\delta) + \delta R/2(1-\delta)\} + (1-p)^2\delta\pi_{m11},$$

from which we obtain:

$$\pi_{m11} = \{R(p^2+p(1-p)(1+\delta))\}/(1-\delta)[1-\delta(1-p)^2].$$

Similarly for the cost:

$$c_{m11} = 2C + 2(1-p)p\delta C + (1-p)^2\delta c_{m11},$$

from which we obtain:

$$c_{m11} = 2C[1+\delta p(1-p)]/[1-\delta(1-p)^2].$$

We denote the expected net benefit under parallel experimentation in the M-form as M_{11}. That is,

$$M_{11} = \pi_{m11} - c_{m11}.$$

Lemma 3: Under the M-form, parallel experimentation always yields higher expected benefits and lower expected costs than immediate full change:

$$\pi_{m11} > \pi_{m2} \text{ and } c_{m11} < c_{m2}.$$

If two independent blueprints are available, then it is always better to try one in each unit rather than one in both units. Why do two independent experiments always give higher expected benefits than two perfectly correlated experiments? In the first period, the two will give the same expected outcome but since two independent experiments have a higher probability of at least one success, success will tend to be implemented earlier with independent experiments. Similarly, the reason for the lower costs with two independent experiments is that under the latter, the probability that no further cost will be paid next period is $1-(1-p)^2$ whereas it is only 1-p under two perfectly correlated experiments.

Lemma 4: Under the M-form: (1) parallel experimentation has both higher expected benefits and expected costs than experimentation in one unit:

$$\pi_{m11} > \pi_{m1} \text{ and } c_{m11} > c_{m1}.$$

(2) parallel experimentation has higher net expected benefits than experimentation in one unit if and only if

$$C < C^* = pA(1+\delta(1-p)^2)/2[1-\delta+\delta p(1-p)(1-\delta(1-p))]+(1-\delta(1-p)^2).$$

The higher benefit of parallel experimentation compared to experimentation in one unit is due to two reasons. First, it has a higher first period expected benefit ($pR > pR/2 + 1/2$ because $pR > 1$ (by Assumption 1). Second, the former has a higher probability (i.e., $1-(1-p)^2$) than the latter (i.e., $1-p$) to have a known good blueprint from the second period onward.

The reason why parallel experimentation has higher costs than experimentation in one unit is that under the former at least 2C always has to be paid out up front. Note that both c_{m11} and c_{m1} decline with p. The former declines faster than the latter as under M_{11} learning about a success is faster. Nevertheless, when p approaches 1, c_{m11} approaches 2C while c_{m1} approaches $C(1+\delta)$, which still remains smaller.

Looking at the difference $(M_{11} - M_1)$, we have:

$$d(M_{11} - M_1)/dp = R(1+\delta(1-p)^2)-2pR\delta(1-p)-2C[\delta(1-2p)(1-\delta(1-p))+\delta^2p(1-p)]-2\delta(1-p)$$

$$= R(1+\delta(1-p)(1-3p))-2C\delta[1-2p-\delta(1-p)(1-3p)]-2\delta(1-p)$$

$$= \delta(1-p)(1-3p)(R+2C\delta)+R-2C\delta(1-2p)-2\delta(1-p).$$

There is thus a non-linear relationship between p and $(M_{11} - M_1)$. Comparing the net benefits in M_{11} and M_1 is therefore complicated. But one sees intuitively that the lower C is relative to R, the higher the advantage of M_{11} over M_1, and vice versa.

We can now summarize the comparison between various organizational forms:

Proposition 5: (1) The U-form has higher expected net benefits than all other organizational forms if $\lambda = 1$ and either $p = 1$ or $C > C^{**} = pR\delta(1-p)^2/[1-\delta(1-p)^2(1+2\delta p)]$.

(2) Experimentation in one unit under the M-form dominates if λ is low enough and $C > C^*$.

(3) Parallel experimentation under the M-form dominates if either $\lambda = 1$ but $C < C^{**}$ or if λ is low enough, $p > \underline{p}$ or $C < C^*$.

The U-form dominates when communication quality is high and either setup costs are high or there is no uncertainty about the experiment. The M-form with experimentation in one unit dominates when communication quality is low and setup costs are high; it dominates with parallel experimentation either when costs are low enough (in which case it dominates the U-form) or when communication quality is low enough but setup costs are sufficiently low and the probability of success sufficiently high (in which case it dominates partial experimentation). A major difference between Propositions 4 and 5 is as follows. When parallel experimentation is not available, the flexibility advantage of the M-form can be achieved when setup costs are high and the probability of success is low, whereas when parallel experimentation is available an additional flexibility advantage of the M-form can be achieved when setup costs are low and the probability of success is high.

V. Coordination on Attribute Compatibility

In this section we extend our coordination concept to incorporate attribute compatibility between tasks iA and iB (i = 1, 2). We will focus on the trade-off between better matching under the M-form and better compatibility under the U-form. Therefore, we abstract from setup costs and assume C = 0 to make this trade-off clear. We assume that the dimension of attributes for which compatibility between tasks iA and iB is required is of order k. We assume that $k \leq 1$, which represents the idea that the attributes to be made compatible typically have a lower dimension than the attributes to be matched. Indeed, remember that compatibility concerns attributes of similar tasks which in general are not matched together but rather act as substitutes for one another. Whereas matching is the rule for complementary parts, substitution is not necessarily the rule for similar parts.

Under the U-form, unit managers coordinate compatibility between tasks iA and iB within each unit. Because they do not need to communicate with other managers, compatibility will be achieved perfectly inside each unit of the U-form. Under the M-form, unit managers must send messages about shocks concerning attribute compatibility to the top manager who is responsible for attribute compatibility. The probability of a message being correctly received by the top manager is λ^k.

In the example of innovation in truck manufacturing, bearings for the model A truck should be compatible with bearings for the model B truck, and similarly for the transmission systems for the two models. Otherwise, even if the two trucks run well, the lack of service (or higher costs of inventories) due to the incompatibility of the two models will lower the value of the new truck. In the example of enterprise restructuring and the social safety net, if the layoff policies in the two regions are not compatible, inefficient close-downs may occur. Similarly, if the rules of eligibility for compensations in the social safety net are not compatible across regions, sub-optimal labor mobility may result.

We assume the following payoff structure when compatibility is required in addition to attribute matching. Again, let the status quo payoff be 1/2. Consider the payoffs for product A under reform (payoffs for B are defined symmetrically). Suppose the blueprint is good, then (i) with change in task 1A but not in task 2A (or change in task 2A but not in task 1A), the payoff is (R+1)/4 if the attributes between 1A and 2A are matched, and the attributes between 1A and 1B and those between 2A and 2B are compatible, otherwise 0; and (ii) with reform in both tasks 1A and 2A, the payoff is R/2 if the attributes between 1A and 2A are matched, and the attributes between 1A and 1B and those between 2A and 2B are compatible, otherwise 0. If the program is bad, then the payoff is always 0.[9]

Under the U-form, because coordination on compatibility is perfect, the expected payoff is the same as in the case without attribute compatibility analyzed in section III. But, the expected payoffs of the M-form will be different. Local managers will continue to make perfect attribute matching in both units. In the M-form without experimentation, the top manager now receives four messages from the two local managers about compatibility shocks. Therefore, we can write down the expected payoff under M-form as

$$\pi_{m2} = p\{\lambda^{4k}R/(1-\delta) + \delta(1-\lambda^{4k})\pi_{m2}\} + (1-p)\delta\pi_{m2},$$

from which we obtain:

$$\pi_{m2} = pR\lambda^{4k}/\{(1-\delta)[1-\delta[p(1-\lambda^{4k})+(1-p)]]\}.$$

[9] The assumption here that the payoff is zero when attributes between tasks iA and iB are not compatible is made for simplicity. It makes the disadvantage of the M-form in coordinating compatibility the highest. In addition, the assumption that compatibility is not achieved if any one message is wrong also simplifies the analysis. Relaxing either of these assumptions will not change our results qualitatively.

Now consider the experimentation approach in the M-form. Suppose a blueprint is tried in unit A, and unit B remains unchanged. With probability 1-p, the program is bad. Therefore, the payoff in A is 0. However, with probability λ^{4k}, compatibility is achieved and the unreformed unit B produces payoff 1/2. With probability $1-\lambda^{4k}$, the payoff in B is 0 due to compatibility failure. In period 2, we are back to the situation of period 1. With probability p, the program is good. In this case, with probability λ^{4k}, compatibility is achieved, and the total payoff is (R+1)/2. In the next period, the same reform program is used in B. However, the managers in the two regions still need to communicate with the top manager for the purpose of coordination on compatibility between tasks iA and iB. Thus, there is a probability of $1-\lambda^{4k}$ that the coordination on compatibility will fail: in such a case, the payoff will be 0 and we will be back to the situation of period 1. Therefore, we have,

$$\pi_{m1} = p\{\lambda^{4k}[(R+1)/2 + \delta\pi_k] + (1-\lambda^{4k})\delta\pi_{m1}\} + (1-p)[\lambda^{4k}/2 + \delta\pi_{m1}],$$

where π_k is the expected payoff from two regions when four messages need to be reported to the top manager for coordination on compatibility:

$$\pi_k = \lambda^{4k}R/(1-\delta) + (1-\lambda^{4k})\delta\pi_k,$$

which gives:

$$\pi_k = \lambda^{4k}R/\{(1-\delta)[1-(1-\lambda^{4k})\delta]\}.$$

Therefore, we obtain:

$$\pi_{m1} = \{p\lambda^{4k}[(R+1)/2+\delta\pi_k]+(1-p)\lambda^{4k}/2\}/\{1-\delta[p(1-\lambda^{4k})+1-p]\}.$$

Because of Assumption 1, $pR > 1$, then we have:

Lemma 5: Under the M-form experimentation in one unit is always dominated by immediate full change: $\pi_{m2} > \pi_{m1}$.

Without the setup costs, there is no benefit from waiting as long as a blueprint is attractive (in expected terms) on a per-period basis. In this case, experimentation cannot be a good strategy.

<u>Proposition 6:</u> Comparing immediate full change under the M-form and the U-form:

(1) $\pi_{m2} = \pi_{u2}$ for $\lambda = 1$. For $\lambda < 1$, there exists $k^*(\lambda, p) > 0$ such that $\pi_{m2} > \pi_{u2}$ if and only if $k < k^*(\lambda, p)$. In particular, for $p = 1$, $k^*(\lambda, 1) = 1/2$.

(2) There exists $k^*(\lambda)$, where $0 < k^*(\lambda) < 1/2$, such that:

(i) for $k < k^*(\lambda)$, $\pi_{m2} > \pi_{u2}$ for all p;

(ii) for $k^*(\lambda) < k < 1/2$, there exists p such that $\pi_{m2} > \pi_{u2}$ for $p > p$ and $\pi_{m2} < \pi_{u2}$ otherwise; and

(iii) for $k > 1/2$, $\pi_{m2} < \pi_{u2}$ for all p.

The first part of Proposition 6 says that the tradeoff between the M-form and the U-form is that between the ability of coordination on attribute matching and that on compatibility. When coordinating compatibility is less demanding (i.e., $k < k^*$), then the M-form has an advantage over the U-form. On the other hand, if coordinating compatibility is very demanding (i.e., $k > k^*$), coordination becomes less of a problem in the U-form than in the M-form; consequently, the U-form will dominate the M-form.

The second part of Proposition 6 says more. When attribute compatibility is not important compared to attribute matching inside an organization (for example, through standardization in the market), then the M-form is better than the U-form. When attribute compatibility is moderately important, then the M-form is better than the U-form if uncertainty of the blueprint is low, but the U-form is better if the uncertainty is high. The reason is that π_{m2} increases faster than π_{u2} when p increases for moderate values of k. When attribute compatibility is very important, than the U-form is always better.

VI. Applications

In this section we apply our theory to three areas: business firms; transition economies; and the organization of government.[10]

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[10] There exist alternative theories for each story. Here, we only discuss the relevant aspects concerning task coordination in these stories. Therefore, our interpretation is often complementary to other theories.

A. Business Firms

We revisit the famous cases documented by Chandler (1962, 1977), all of them showing coordination failures between production and sales under a U-form when a corresponding firm introduced new products or adopted innovations. These coordination failures were a major impetus for the subsequent change of organizational form in these corporations from a U-form to an M-form. While the emerging M-form had many different varieties such as organization by geography, product, process, etc, they shared a common feature that units became self contained. Our theory can interpret the coordination failures under the U-form in a consistent way.

The first case is about du Pont. Before 1921, du Pont was organized as a U-form: under the headquarters there were functional units for production and sales respectively. After World War I du Pont expanded production from explosives to consumer products, such as paints (Chandler, 1962, pp. 78-94). At that time, whenever a new chemical was developed which changed the attributes of explosives and paints, the production unit reported the attribute change to headquarters, which then sent commands to the sales unit. Then the sales unit learned the attributes of the new product and demonstrated them to customers. At the same time, the sales unit learned customers' preferences and translated them into a new set of attributes.

The expansion of product lines caused major coordination troubles in du Pont: there were too many mistakes and inertia in adjusting attributes. Du Pont started to have losses. The problem became most evident in 1919 when almost all the new final products, which required a great deal of coordination, had (sometimes heavy) losses. In contrast, in the same year nearly all the traditional du Pont products which did not require much coordination made profits (Chandler, 1962, p. 95). Moreover, while du Pont suffered heavy losses for some new products such as paints, most of its competitors who were specialized in paints did not have similar coordination problems and "were enjoying one of their most profitable years" (Chandler, 1962, p. 92). In the early 1920, a subcommittee under the Executive Committee at du Pont investigated and concluded that "the underlying problem was not one of selling, but organization." The subcommittee proposed to change du Pont into a multi-divisional organization. This conclusion was further confirmed when du Pont suffered even bigger losses in 1921 after every effort was made to improve informational channels while keeping the U-form under the President Irénée du Pont (Chandler, 1962, pp. 96-101). Later in 1921, failure to improve the organization's performance and the persistent losses convinced du Pont to reorganize the firm into an M-form. This solved the problem, and the organizational form has been kept stable since then (Chandler, 1996, pp. 104-113).

The second case is about Sears Roebuck & Co. Before 1925, Sears, the largest mail-order firm in the U.S., was organized as a U-form. At the headquarters in Chicago, there were departments responsible for specialized functions nationwide, such as the Merchandise Department responsible for procurement, the Catalogue and Advertisement Departments responsible for sales, and the Operating Department responsible for distributing commodities from producers to customers (Chandler, 1962, pp. 226-232). The U-form structure worked well when the number of regions covered and the number of stores was not too large.

When Sears expanded into many new territories, acquired a large number of new stores and factories, and involved in new businesses such as retailing, its coordination problems became severe. Many idiosyncratic regional issues were hard to manage through separate functional departments. To manage the vast multi-regional mail-order/retail network while keeping the U-form structure, Sears put territorial officers in charge of handling territorial-specific issues by giving them authority on their region's personnel issues (Chandler, 1962, pp. 253-256). However, without the authority to coordinate problems locally, this structure did not work. In fact, on many occasions, instead of reporting to functional departments, local shops often relied on territorial officers to solve their problems (Chandler, 1962, p. 259). In 1939 Sears started a reorganization based on a territorial principle and completed in 1948: under the headquarters there were multi-functional and autonomous territorial divisions, such as the Midwestern Zone, the North-Western Zone, the North Central Zone, etc (Chandler, pp. 268-282).[11]

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[11] A similar story holds for the Ford Motors Company. Before World War II, with a U-form organization and a focus on the Model-T car, Ford was the largest car producer in the U.S. and its engineers were among the most innovative. Ford also developed inexpensive tractors and technically excellent airplanes. However, the separated production and sales structures led to a poor coordination between production and sales. Eventually, Ford failed in producing and selling tractors and air planes although technically it made them well (Chandler, 1962, p. 301, pp. 372-373).

B. Transition Economies

We may regard a centrally planned economy as a huge "firm" with the national government as the headquarters and ministries or subnational governments as sub-units of the firm. From this perspective, Eastern Europe and the former Soviet Union (EEFSU) economies were organized as a gigantic U-form, where each state-owned enterprise was under the control of a single ministry which specialized in administering one type of product. On top of that, there was a high degree of regional industrial concentration.[12] This central planning structure makes central coordination essential: In the late 1970s the *Gosplan*, which supervised all specialized ministries, was responsible for 48,000 plan "positions" and 12 million products (Nove, 1983).

In contrast, the Chinese economy was organized as an M-form, where most state-owned enterprises were under the control of regional governments. At the same time, industries were much less regionally concentrated than the EEFSU and the average size of Chinese enterprises was much smaller too. Typically, the production of each region was relatively self-contained. With regional governments taking major responsibilities for coordination, the central government's role of coordination was greatly reduced compared to that in the EEFSU. The Chinese State Planning Commission was never responsible for more than 1,000 products (Qian and Xu, 1993), and the central statistical agency in China had total staff of only 280 (in 1981), compared to 41,000 in the Soviet Union (in 1987) (Huang, 1994).[13]

In our theoretical model we made a symmetry assumption with two industries in each region to make the analysis non-trivial. However, in reality, China and the Soviet Union had different patterns of industrial concentration, on top of the organizational form. In China, because of regional industrial

[12] In the Soviet Union, for example, a large number of consumer goods and producer goods (e.g. sewing machines, freezers, hydraulic turbines, and 87 percent of all the 5,885 products in machine building industry) had only a single producer located in one geographic area. In 1988, about two thirds of all the products had no more than three producers (IMF et al., 1991, Vol. II, pp.39-40).

[13] We further note that the different organizational forms between China and the EEFSU is not due to the different sizes of the corresponding economies. In fact, China's central statistical agency was even smaller than that in Hungary, which is about 100 times smaller than China in terms of population. A comparison between Hungary and a small Chinese province, Hainan, may further illustrate the point. Hungarian ministries controlled most of the firms before the transition. However, the control of firms in Hainan is distributed at different levels of hierarchy, although Hainan is smaller than Hungary, in terms of both population and GDP.

dispersion, the M-form (regional-based) and the U-form (industrial-based) represented two different potential organizational forms and the Chinese adopted the former. In the Soviet Union, the initial U-form organization led to extreme industrial concentration where one region had only one industry. In that case, regions are not self-contained any more which means that the properties of the M-form cannot be obtained simply by devolution of powers to the regions. The initial choice of organizational form thus had an impact on location and size of industry. That is, the initial choice of organizational form had an impact on the evolution of location and concentration of industries in an economy. In the Soviet Union, these choices represented a "lock-in" of the U-form, making a change towards the M-form impossible without major industrial investment. This consideration also clarifies the confusion arising frequently in studying the Soviet Union and Russia. It is often thought that the devolution of authority to regional governments under Yeltsin in Russia after 1992 represents a shift from a U-form to an M-form. However, this is only a superficial change since such a change only represents a shift from a U-form, as we have studied, to a "collapsed" U-form, which is equivalent to a U-form where the communication between local and central managers has completely broken down. This is because when industries are regionally concentrated and cannot be moved around easily, regions cannot be self-contained units as in the case of China. Therefore, our theoretical framework sheds new light on the troubles that Russian transition is currently facing.

According to our theoretical analysis, the introduction of reforms (be they reforms within the central planning system or market-oriented reforms) in the EEFSU requires a comprehensive approach with coordination from the center. On the other hand, in China, reforms can proceed with local experiments, or even parallel experiments, because coordination is established locally. Indeed, plagued by many coordination problems, many previous reform experiments in the EEFSU were not successful. In contrast, China repeatedly adopted successfully an experimental approach to reforms.

Consider the agricultural reform. Under the U-form organization of Soviet agriculture, tractors were provided centrally by the so-called MTS stations. The tasks of providing inputs to the farmers and managing their operations, storage, processing, transport, and road infrastructure were all allocated to separate agencies (van Atta, 1993a). Warehouses and processing plants were more likely to be located hundreds of miles away from farms. Farming was subordinate to at least 8 different ministries (Butterfield, 1990). The political motives for such a design of economic institutions were to prevent the reemergence of independent, private farms by making farming completely dependent on the specialized organization of production. Local authorities had no control over farming and played mainly a role of expediters, throwing themselves into the search for batteries, belts and harvester blades, and undoing complex knots in the supply system (van Atta, 1993b). There were serious coordination problems. These coordination problems could not be solved within the U-form despite repeated attempts to improve the situation. For example, in the 1980s a structure called RAPO (*raïonnoe agropromyshlennoe obyedinenie*) was created with the task to locally coordinate activities between the various ministries. Nevertheless, the existing U-form structure was kept in place. This led to a conflict of authority between the functional ministries and the new local coordination structure. The RAPOs did not have power over the resources controlled by the ministries and they were generally ignored by the latter. Other attempts at reforms, such as the introduction of an overarching ministry *Gosagroprom*, the introduction of agrofirms at a smaller scale and even the introduction of leasing contracts (*arenda*), also failed to improve coordination (Butterfield, 1990). When the Soviet system collapsed, the U-form organization had left a difficult legacy for potential private Russian farmers: an important dependence on machinery and supplies, outside transport and storage, high capital requirements, etc.

The lack of development of private farming in the Soviet Union stands in stark contrast to the success of the Chinese agricultural decollectivization. In China, the well-publicized agricultural household responsibility system was developed through the initiative of local governments. Local government officials in Fengyang County, Anhui Province, took the initiative and coordinated related tasks, such as land distribution, grain procurement, chemical fertilizer supply, etc. It is only later that the central government endorsed and promoted such a practice nationwide.[14]

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[14] Similarly to agriculture, the differences in organizational form also account for the differences in privatization policies in China and Russia. After the collapse of the Soviet Union, Russia's mass privatization program was coordinated from the center. Given the industrial structure inherited from the U-form organization, local initiatives to privatize large enterprises could have created problems given both the extreme form of specialization and the geographical dispersion of complementary assets. In China, by contrast, privatization was

C. The Organization of Government and the Foundations of Federalism

Two organizational forms of government have received much attention: the unitary state and the federal state. Our analysis starts to provide a theoretical foundation of both, especially federalism. France and Japan, among others, have a unitary state, and their governments are mainly organized along functional lines where specialized ministries concentrate most powers, leaving regional governments with relatively little authority.[15] The organizational form of the U.S. government is a primary example of federalism. The fifty states have the constitutional rights and responsibilities for coordinating government activities inside their jurisdictions. This spawns an environment for state governments themselves to try innovative policies independently without approval from the federal government.

It has been perceived a long time ago that the American federal system may facilitate experimenting innovative policies. It was argued in 1888 that "federalism enables people to try experiments which could not safely be tried in a large centralized country" (Bryce, 1901). A few decades later, the American Supreme Court Justice, Louis Brandeis, had a famous characterization of American federalism as the "laboratory of the states." By laboratories, he meant that the states could experiment with new solutions to social and economic problems. Those that worked could be applied nationally; those that failed could be discarded. He said in 1932 that "it is one of the happy incidents of the federal system that a single courageous state may... serve as a laboratory; and try novel societal and economic experiments without risk to the rest of the country" (Osborne, 1988).

Indeed, many changes of government policies in the U.S. were first initiated by some states, and only later these experiments were imitated by other states. To illustrate how federalism provides a flexible

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mainly driven by local government initiatives. Experiments of privatization began in some counties (e.g. Yibin of Sichuan Province, Shunde of Guangdong Province, and Zhucheng of Shandong Province) around 1993. Having control over most of the related issues, county governments could try out different ways of privatizing according to the local environment. Indeed, in the privatization process county governments took responsibility to coordinate most of the related activities and policies, such as issues concerning corporate governance, ownership structure, bad debts, taxes, and excess workers, etc. This experimental approach not only makes local privatization smooth, it helps other regions as well. By imitating some of the successful experiments, in 1996, many small SOEs had been privatized.

[15] It is interesting to note that France introduced some decentralization of power in 1981.

mechanism for state governments to coordinate policy experiments, we give an example of the state support of high tech business in the last quarter of the twentieth century. Specifically, the state government coordinated several activities ranging from the reform of the public education system, to the creation of private and public venture capital funds, and to the set up of programs to match local academia and business to advance technological innovation. The states of Massachusetts and California took the lead in these “experiments.” It is documented (Osborne, 1988) that in 1975 the Massachusetts government introduced a set of innovative policies in the aspects of public education, venture capital, small business, and tax policy to assist emerging high tech industries. The most innovative part of the initiative is to coordinate those institutions such as education/research institutions, business, and government, which traditionally do not work together. Particularly, the state government created or greatly expended community college education to increase the supply of skilled labor, and helped start-up high tech firms in easing bureaucracies and in finance. The turn-around of Lowell near Boston in the 1970s provides an example. The whole set of complementary state programs, from public education, highways to venture capital financing, had played roles in attracting and promoting high tech companies in this old declining town. As a result Lowell revived to become one of the most successful high tech business towns in the U.S. by the late 1970s (Osborne, 1988, pp.23-24).

Later, a federal government agency, the Council of State Planning Agencies (CSPA), propagated Massachusetts’s experiences to other states. Influenced by the CSPA, California government initiated programs to reform its public education. It established a network of centers to train teachers in the use of computers; upgraded the state engineering schools; and proposed new high school curricula. Moreover it implemented state programs that coordinated activities between universities and business. For instance, the government offered matching funds to any microelectronics research grant made by a California business to a university of California faculty member (Osborne, 1988, pp.35-39).

Experiments in Massachusetts and California further had an impact on other states. In the early 1980s, many state task forces had visited Route 128 in Massachusetts and the Silicon Valley in California to learn how state and local governments successfully supported high tech businesses. For instance, community college education was rare before the mid-1970s. However, following the models of Massachusetts and California it has become a standard public education institution in most states since and has played important roles in supplying skilled labor force for the high tech businesses. These are only an example among many. In fact, there is a large literature in political science and sociology examing the timing of policy imitation across states in the U.S. since an experiment has conducted by one state. That literature gives statistical evidence on how a new policy is imitated from its first experiment in one state to other states, and the records date back to the late 18th century (Gray, 1994; and Oates, 1999). It has documented various innovation adoption paths of a large number of policy experiments across states. For example, the state-boards-of-education system was first tried in one state in 1784, and was adopted by 40 states in 1949; while the degree-requirement-for-elementary-school-teaching policy was first started in one state in 1930 and was adopted by 46 states in 1969 (Gray, 1973).

VII. Concluding Remarks

In this paper we introduced a method of modelling task coordination inside an organization as "attribute matching." Using this method, we developed a theoretical analysis of organizational forms in order to understand the performance of the M-form and U-form organizations in coordinating changes. Our theory sheds new light on business organizations, transition economies, and the organization of government.

Our paper seems to be the first formal attempt to study how the M-form and U-form affect coordination problems within an organization. The paper mainly tries to provide a new conceptual framework while deriving some predictions on the superiority of the M-form or the U-form, depending on the quality of communication within organizations, the uncertainty of innovations, and the costs of introducing innovations. This paves the way for further empirical analysis in the comparison of organizations in the future.

The application of our analysis to transition economies opens new perspectives on understanding how the differences in organizational forms in the EEFSU and China affected their transition paths. For the first time, we formally address the following questions: Why is China special in its use of experimental approaches? Why is the U-form not suitable for doing local experiments? The importance of understanding these questions lies in the fact that in the EEFSU, some experimental reforms that were introduced before their transition failed. On this basis, the regional experimental approach to reforming a planned economy has been discredited and abandoned during later transitions in these economies.

The difference between the M-form and the U-form is highly relevant in other aspects. Note first that the consequences of a collapse of power at the center are much smaller in the M-form. For example, during the Cultural Revolution (1966-1976), the Chinese central government almost completely lost its ability to coordinate the economy, but the national economy did not collapse: National income dropped in two years (-7.2% in 1967 and -6.5% in 1968) and recovered quickly afterwards without much central government coordination.

In the context of transition and price liberalization where government coordination is replaced by market forces, the output response is likely to be different in both organizational forms. In a U-form economy with greater induced specialization and more widespread monopolies, price liberalization gives smaller outside options to firms in the domestic economy in terms of finding new suppliers and/or clients while making disruptions of existing output links more dramatic, which is much in line with the output fall models of Blanchard and Kremer (1997) and Roland and Verdier (1999). Blanchard and Kremer (1997) have emphasized the role of complexity in technological complementarities between firms in generating disruption. In our framework, complexity is not simply an exogenous technological variable. The choice of technology is affected by the organizational form. Even for a given technology, the M-form reduces the complexity of coordination because of the decentralization of decision-making to self-contained units. In contrast, by centralizing communication on attribute shocks, the U-form makes coordination more complex.

In the U-form economy, the higher degree of monopolization is likely to give single firms more holdup power over the government, possibly leading to more rent-seeking and soft budget constraints, whereas in the M-form economy competitive forces are likely to develop more easily from scratch, with single firms having less holdup power and less leverage via the government. The larger firms left by the U-form economy are likely to require more sophisticated management expertise to operate in the global economy compared to their counterparts in the M-form organization. A lack of fulfillment of requirements in terms of management expertise may lead to more disappointing results of privatization.

Appendix. Mathematical Proofs

Proof of Lemma 1: (1) Because

$$\pi_{u2} = 2p\pi[1 - (1-\lambda^2)^2\delta]/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\},$$

where both $\pi = \lambda^2 R/\{2(1-\delta)[1-(1-\lambda^2)\delta]\}$ and $[1-(1-\lambda^2)^2\delta]/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}$ increases in λ (the latter because $[1-x\delta]/\{1-\delta[px+(1-p)]\}$ decreases in x), then π_{u2} increases in λ.

(2) $c_{u2} = C/\{1-[p(1-\lambda^2)^2+(1-p)]\delta\}$ decreases in λ.

$c_{u2} < c_{m2}$ if and only if

$1 - \delta(1-p) < 2[1-\delta(p(1-\lambda^2)^2+1-p)]$

if and only if

$2\delta p(1-\lambda^2)^2 + \delta(1-p) < 1$,

which is valid for all λ provided $\delta < 1/(1+p)$.■

Proof of Proposition 1: (1) By Lemma 1, at $\lambda = 1$, $\pi_{u2} = \pi_{m2}$; but $c_{u2} = C/(1-\delta(1-p)) < c_{m2} = 2C/(1-\delta(1-p))$, then $U_2 > M_2$. Also by Lemma 1, π_{u2} increases in λ and c_{u2} decreases in λ, then $U_2 = \pi_{u2} - c_{u2}$ increases in λ. Because M_2 is independent of λ and because U_2 goes to 0 as λ decreases, then for p and C given there exists $\lambda_{mu} > 0$ such that $M_2 > U_2$ if and only $\lambda < \lambda_{mu}$.

(2) For any $\lambda < 1$, $M_2 > U_2$ at $C = 0$. When $c_{u2} < c_{m2}$, c_{m2} also increases faster than c_{u2} as C increases, therefore, for p and λ given, such a C_{mu} exists. (U_2 could be the same as M_2 if both have the same value as the status quo at C_{mu}.)

Proof of Lemma 2: (1) Note that $pR(1+\delta)/2+(1-\delta)/2$ is a weighted sum of pR and 1. Therefore, because $pR > 1$ by Assumption 1, then the sum is less than pR, or $\pi_{m1} < \pi_{m2}$.

(2) Because $d\pi_{m1}/dp = [R(1+\delta)/2 - \delta/2]/[1-(1-p)\delta]^2$ and $dc_{m1}/dp = -\delta^2 C/[1-(1-p)\delta]^2$, we have:

$$dM_1/dp = [R(1+\delta)/2 - \delta/2 + \delta^2 C]/[1-(1-p)\delta]^2 > 0.$$

Also because $d\pi_{m2}/dp = R/[1-(1-p)\delta]^2$ and $dc_{m2}/dp = - 2C\delta/[1-(1-p)\delta]^2$, then we have

$dM_2/dp = \{R + 2C\delta\}/[1-(1-p)\delta]^2 > 0$.

Therefore, by $R(1+\delta)/2 < R$, $\delta C - 1/2 < 2C$, we have $R(1+\delta)/2 - \delta/2 + \delta^2 C < R + 2C\delta$, then, $dM_2/dp > dM_1/dp > 0$.■

Proof of Proposition 2:

(1) Because

$M_1 - M_2 = \{pR/2(1+\delta) + (1-\delta)/2 - pR - (1-\delta)C(1+p\delta) + 2C(1-\delta)\}/(1-\delta)[1-\delta(1-p)]$

$= [C(1-p\delta)-(pR-1)/2]/[1-\delta(1-p)]$,

then $M_1 > M_2$ if and only if $p < \underline{p}$. Furthermore, $\underline{p} < 1$ if and only if $R/2(1-\delta) - C > 1/2(1-\delta)$.

From $M_1 = 1/(1-\delta)$ we obtain:

$$p_{m1}^* = (2C+1)(1-\delta)/\{R(1+\delta)-2\delta(C(1-\delta)+1)\},$$

and from $M_2 = 1/(1-\delta)$ we obtain:

$$p_{m2}^* = (2C+1)(1-\delta)/(R-\delta).$$

Then $p_{m1}^* < p_{m2}^*$ if and only if $R/2(1-\delta) - C > 1/2(1-\delta)$.

By Lemma 2, $p_{m1}^* < p_{m2}^*$ must imply that $p_{m1}^* < p_{m2}^* < \underline{p}$.

(2) follows directly from the expression for $M_1 - M_2$.■

Proof of Proposition 3: We note that

$$\pi_{u2} = p\{\lambda^4[R/(1-\delta)] + 2\lambda^2(1-\lambda^2)[R/2(1-\delta) + \delta\pi]\}/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}$$

$$= p\{\lambda^4[R + \delta R/(1-\delta)] + 2\lambda^2(1-\lambda^2)[R/2 + \delta[\pi + R/2(1-\delta)]]\}/\{1-\delta[p(1-\lambda^2)^2+(1-p)]\}.$$

Comparing π_{u2} with π_{u1}, because $R > (R+1)/2$ and $R/2(1-\delta) \geq \pi$, then $\pi_{u2} > \pi_{u1}$.■

Proof of Proposition 4: (1) For $\lambda = 1$, $\pi_{u2} = \pi_{m2} > \pi_{m1}$ and $c_{u2} < c_{m1} < c_{m2}$. Therefore, for λ large enough, by continuity, $U_2 > M_2$ and $U_2 > M_1$.

(2) If λ is small enough, U_2 will always be dominated by M_1 or M_2. The rest of the proposition follows directly from Proposition 2.■

Proof of Lemma 3: $\pi_{m11} > \pi_{m2}$ if and only if

$$\{R(p^2+p(1-p)(1+\delta))\}/(1-\delta)[1-\delta(1-p)^2] > pR/\{(1-\delta)[1-(1-p)\delta]\},$$

if and only if

$$[1-\delta(1-p)](p^2+p(1-p)(1+\delta)) > p(1-\delta(1-p)^2),$$

if and only if

$$[1-\delta(1-p)](1+\delta(1-p)) > 1-\delta(1-p)^2,$$

if and only if

$$1-\delta^2(1-p)^2 > 1-\delta(1-p)^2,$$

which is verified since $\delta < 1$.

Similarly, $c_{m11} < c_{m2}$ if and only if

$$2C[1+\delta p(1-p)]/[1-\delta(1-p)^2] < 2C/[1-(1-p)\delta],$$

if and only if

$$(1-\delta(1-p))(1+\delta p(1-p)) < 1-\delta(1-p)^2$$

if and only if

$$\delta^2 p(1-p)^2 > 0,$$

which is verified.■

Proof of Lemma 4: (1) $\pi_{m11} > \pi_{m1}$ if and only if

$$\{R(p^2+p(1-p)(1+\delta))\}/(1-\delta)[1-\delta(1-p)^2] > [pR(1+\delta)+(1-\delta)]/2(1-\delta)[1-(1-p)\delta],$$

if and only if

$$2\{R(p^2+p(1-p)(1+\delta))\}[1-(1-p)\delta] > [pR(1+\delta)+(1-\delta)][1-\delta(1-p)^2],$$

if and only if

$$[2pR][1-\delta^2(1-p)^2] > [pR(1+\delta)+(1-\delta)][1-\delta(1-p)^2].$$

Because $pR > 1$ if and only if $2pR > pR(1+\delta)+(1-\delta)$, furthermore, $1-\delta^2(1-p)^2 > 1-\delta(1-p)^2$, then the above inequality holds.

Similarly, $c_{m11} > c_{m1}$ if and only if

$$2C[1+\delta p(1-p)]/[1-\delta(1-p)^2] > C(1+p\delta)/[1-(1-p)\delta],$$

if and only if

$$2 - 2\delta(1-p)^2 - 2\delta^2 p(1-p)^2 > 1 - \delta(1-p)^2 + p\delta - \delta^2 p(1-p)^2,$$

if and only if

$$1 > \delta[p + (1-p)^2 + \delta p(1-p)^2],$$

if and only if

$$1 - \delta > -\delta p(1-p)(1-\delta(1-p)),$$

which is always valid since $1 > \delta(1-p)$.

(2) $M_{11} > M_1$ if and only if

$$\{R(p^2+p(1-p)(1+\delta))-2C(1-\delta)(1+\delta p(1-p))\}[1-\delta(1-p)]$$

$$> \{pR(1+\delta)/2+(1-\delta)/2-C(1-\delta)(1+p\delta)\}[1-\delta(1-p)^2]$$

if and only if

$$R(p^2+p(1-p)(1+\delta)-pR(1+\delta)/2-(1-\delta)/2+C(1-\delta)(1+p\delta)-2C(1-\delta)(1+\delta p(1-p))$$

$$> \delta(1-p)\{R(p^2+p(1-p)(1+\delta))-2C(1-\delta)(1+\delta p(1-p))-(1-p)[pR(1+\delta)/2+(1-\delta)/2-C(1-\delta)(1+p\delta)]\}$$

if and only if

$$(pR-1)(1-\delta)/2+pR\delta(1-p)-C(1-\delta)[1-p\delta(2p-1)]$$

$$> \delta(1-p)\{pR[1+\delta(1-p)+p]/2-(1-p)(1-\delta)/2-C(1-\delta)(1+p+\delta p(1-p))\}$$

if and only if

$$(pR-1)(1-\delta)/2+pR\delta(1-p)-\delta(1-p)[pR(1+\delta(1-p)+p)/2-(1-p)(1-\delta)/2]$$

$$> C(1-\delta)[1-p\delta(2p-1)]-\delta(1-p)C(1-\delta)(1+p+\delta p(1-p))$$

if and only if

$$(pR/2)[1-\delta+2\delta(1-p)-\delta(1-p)(1+p+\delta(1-p))]-(1-\delta)(1-\delta(1-p)^2)/2$$

$$> C(1-\delta)[1-p\delta(2p-1)-\delta(1-p)(1+p+\delta p(1-p))]$$

if and only if

$$(pR/2)[1-\delta+\delta(1-p)(1-p-\delta(1-p))]-(1-\delta)(1-\delta(1-p)^2)/2$$

$$> C(1-\delta)[1-\delta+\delta p(1-p)(1-\delta(1-p))]$$

if and only if

$$pR(1+\delta(1-p)^2) > 2C[1-\delta+\delta p(1-p)(1-\delta(1-p))]+(1-\delta(1-p)^2).\blacksquare$$

Proof of Proposition 5: (1) If p=1, we know from proposition 2 that M_2 dominates M_1. It is easy to check that M_{11} and M_2 are equivalent and equal to R/(1-δ) - 2C. If $\lambda = 1$, then $U_2 = R/(1-\delta) - C$ which clearly dominates. If p < 1 but $\lambda = 1$, $U_2 > M_1$, because $\pi_{u2} = \pi_{m2} > \pi_{m1}$ and $c_{u2} < c_{m1}$. At $\lambda = 1$, $U_2 > M_{11}$ if and only if

$$[pR-C(1-\delta)]/(1-\delta)[1-\delta(1-p)] > \{pR(1+\delta(1-p))-2C(1-\delta)(1+\delta p(1-p))\}/(1-\delta)[1-\delta(1-p)^2]$$

if and only if

$$(1-\delta(1-p)^2)(pR-C(1-\delta)) > [1-\delta(1-p)]\{pR(1+\delta(1-p))-2C(1-\delta)(1+\delta p(1-p))\}$$

if and only if

$$pR\{(1-\delta(1-p)^2)-[1-\delta^2(1-p)^2]\} > C(1-\delta)\{(1-\delta(1-p)^2)-2(1+\delta p(1-p))(1-\delta(1-p))\}$$

if and only if

$$-pR\delta(1-p)^2 > -C[1-\delta(1-p)^2(1+2\delta p)]$$

if and only if

$$pR\delta(1-p)^2 < C[1-\delta(1-p)^2(1+2\delta p)].$$

We verify that $1 > \delta(1-p)^2(1+2\delta p)$ for all p and $\delta < 1$. Therefore, when $C > C^{**} = pR\delta(1-p)^2/[1-\delta(1-p)^2(1+2\delta p)]$, $U_2 > M_{11}$ at $\lambda = 1$.

(2) If λ is low enough, then U_2 is dominated. By Lemma 4, M_1 dominates if and only if $C > C^*$.

(3) By Lemma 3, M_{11} always dominates M_2. By Proposition 2, $M_2 > M_1$ for $p > \underline{p}$. Therefore, $M_{11} > M_1$ for $p > \underline{p}$. Again if λ is low enough, U_2 is dominated. The rest follows from Lemma 4. Because M_{11}, M_1 and M_2 are independent of λ, for such p, $M_{11} > U_2$ for low enough values of λ. Similarly, because both M_{11} and M_1 are independent of λ and, by Lemma 4, M_{11} dominates M_1 for $C < C^*$. For any such C, U_2 goes to 0 when λ becomes small, then M_{11} also dominates U_2 for λ low enough. From the proof of (1), we know that $M_{11} > U_2$ if $\lambda = 1$ and $C < C^{**}$.■

Proof of Lemma 5: Because

$$(\pi_{m2} - \pi_{m1})\{1-\delta[p(1-\lambda^{4k})+1-p]\} = p\{\lambda^{4k}(R + \delta R/(1-\delta) - (R+1)/2 - \delta\pi_k\} - (1-p)\lambda^{4k}/2$$

$$= p\lambda^{4k}[R/2 + \delta R/(1-\delta) - \delta\pi_k] + (-p-1+p)\lambda^{4k}/2$$

$$= p\lambda^{4k}\delta[R/(1-\delta) - \pi_k] + \lambda^{4k}(pR - 1)/2.$$

Since $\pi_k = R/(1-\delta)$ for k = 0 and decreases in k, $\pi_k \leq R/(1-\delta)$. Therefore, as $1-\delta[p(1-\lambda^{4k})+1-p] > 0$ and $pR > 1$, $\pi_{m2} > \pi_{m1}$.■

Proof of Proposition 6: (1) Given any $\lambda < 1$ and p, π_{u2} is independent of k and π_{m2} is a decreasing function of k. For $\lambda < 1$, $\pi_{m2} > \pi_{u2}$ at k = 0, therefore, such k* exists. In particular, at p = 1,

$$\pi_{m2}/\pi_{u2} = \lambda^{4k}[(1-(1-\lambda^2)\delta]/\lambda^2[1-(1-\lambda^{4k})].$$

Then $k^*(\lambda, 1) = 1/2$.

(2) We have:

$$\pi_{m2}/\pi_{u2} = \lambda^{4k-2}(1-(1-\lambda^2)\delta)\{1-\delta[p(1-\lambda^2)^2+1-p]\}/[1-\delta(p(1-\lambda^{4k})+1-p)][1-(1-\lambda^2)^2\delta],$$

from which we derive:

$$d(\pi_{m2}/\pi_{u2})/dp > 0$$

if and only if

$$- [1-\delta(p(1-\lambda^{4k})+1-p)][(1-\lambda^2)^2-1] + [1-\delta(p(1-\lambda^2)^2+1-p)][(1-\lambda^{4k})-1] > 0,$$

if and only if

$$(1-\delta)[(1-\lambda^{4k})-(1-\lambda^2)^2] > 0.$$

Let $k^*(\lambda)$ be such that $1-\lambda^{4k^*(\lambda)} = (1-\lambda^2)^2$, then $0 < k^*(\lambda) < 1/2$ and $d(\pi_{m2}/\pi_{u2})/dp > 0$ if and only if $k > k^*(\lambda)$.

By part (1), at p = 1, $\pi_{m2} > \pi_{u2}$ if and only if $k < 1/2$. Then, for $k > 1/2$, $\pi_{m2} < \pi_{u2}$ at p = 1, then $d(\pi_{m2}/\pi_{u2})/dp > 0$ implies that $\pi_{m2} < \pi_{u2}$ for all p. For $k^*(\lambda) < k < 1/2$, $\pi_{m2} > \pi_{u2}$ at p = 1, then $d(\pi_{m2}/\pi_{u2})/dp > 0$ implies that there exists p such that $\pi_{m2} > \pi_{u2}$ for $p > p^*$ and $\pi_{m2} < \pi_{u2}$ for $p < p^*$. For $k < k^*(\lambda)$, $\pi_{m2} > \pi_{u2}$ at p = 1, then $d(\pi_{m2}/\pi_{u2})/dp < 0$ implies that $\pi_{m2} > \pi_{u2}$ for all p.■

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