Coordination and Experimentation in M-Form and U-Form Organizations*

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Abstract

We compare the performance of organizational forms (M-form and U-form) in experimenting with uncertain projects. 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 in "attribute matching" but suffers from coordination in "attribute compatibility" and less gains in specialization. The distinctive advantage of the M-form is its flexibility in choosing between small-scale and full-scale experimentation.

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

James March and Herbert Simon, *Organizations*, 2nd edition, 1993

1 Introduction

Understanding how economic activities are 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. Coordination becomes crucial whenever there is specialization. On the other hand, coordination is also costly, which limits the extent of specialization within organizations (Becker and Murphy, 1992).

In this paper we introduce two types of coordination inside organizations. The first and most important one involves attribute matching of specialized tasks, which are complementary to each other. This concept of coordination is inspired by the notion of "design attributes" first introduced by Milgrom and Roberts (1990, 1992). While Milgrom and Roberts focus on communication in organizations, we examine how alternative organizational forms affect coordination when the need for attribute matching is pervasive. Attribute matching can be understood as assembling complementary parts, such as assembling 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 nets and legal institutions, etc. Each complementary part is characterized by its attributes in dimensions such as time, location, technical specifications, 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. The diameter of a screw must match that of a bolt so that they both meet certain standards of material resistance. In an assembly line 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 software package will not work unless all the subroutines fit to each other, and a conference will be a disaster if room allocation conflicts with other academic programs.

The attribute matching problem is especially pervasive in implementing changes such as innovation and reform. In these situations, it is not sufficient to match all attributes in blueprints. Blueprints are often imperfect and incomplete, leaving room for unexpected contingencies. For example, blueprints for reforms do not specify details of attribute changes, when many of the attributes are not well understood at the time a blueprint is designed. Attribute mismatches in implementing innovations and reforms, which we call "attribute shocks," are thus inevitable.

The second type of coordination refers to the coordination of similar or substitutable tasks, which we call "attribute compatibility." This can be understood as coordination within a process such as production of engines for different types of cars. Car production has a better compatibility if different types of cars share common parts or services. Although both attribute matching and attribute compatibility are activities of coordination, there is a conceptual dichotomy between the two in the following sense. It is indispensable to achieve success in attribute matching because there are drastic consequences when attributes fail to be matched (Kremer, 1993). However, failing to solve satisfactorily attribute compatibility does not have as drastic consequences although it involves losses of scale economies or of positive externalities.

The following example of truck production can be used to illustrate this distinction.We may think of truck production involving two functions: function 1 is to make engines, and function 2 is to make truck bodies. Suppose there are two truck models, GMC Sierra and Chevrolet Silverado. For each model, the attributes of engine and the attributes of truck body should be matched. If some attributes between the engine and the truck body are not matched, the truck cannot operate at all. Suppose a technological innovation in transmission will make a better truck, but it will require a change in the technical specification for engines. Coordination in attribute matching is to find a solution to match engines with the new transmission, for each model. Failure in attribute matching will result in a drastic consequence: the truck with a new transmission won't operate. On the other hand, if GMC Sierra and Chevrolet Silverado can share the same transmission, costs can be lowered, through either reduced production costs or reduced inventory level, which increases the value from both models. Failure to share transmission between the two models would reduce the value, but will not stop the truck from operation.

The quality of coordination depends on the quality of communication inside an organization. The communication problem arises because only managers who directly and frequently engage in a particular task have 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, is relevant here – direct involvement in a task gives rise to good knowledge about that task.

It is important to note that the communication problem is endogenous, depending on how tasks and decision-making authority are assigned within an organization. In line with the literature on organization theory (Chandler, 1962; Williamson, 1975), we define an M-form (multi-divisional form) organization as one that consists of "self-contained units" where complementary tasks are grouped together. In an M-form organization, units are similar to each other, such as the Oldsmobile Division and Chevrolet Division in General Motors in the 1930s. In contrast, a U-form (unitary form) organization is decomposed into "specialized units" where substitutable or similar tasks are grouped together. In a U-form organization, units are complementary to each other, such as the Sales Department and Manufacturing Department in Ford Motors in the 1920s. This definition also corresponds to the product-focused (M-form) and process-focused (U-form) organizational forms in the management literature (see.e.g. Galbraith 1973, Athey and Schmutzler, 1995).

A simple trade-off emerges between two types of coordination and scale economies. In the self-contained units of the M-form, local managers can more easily solve the attribute matching problem among complementary tasks but are less capable of achieving attribute compatibility, and furthermore the advantages of specialization are not fully appropriated due to the duplication of coordination in attribute matching. In the U-form organization, local managers can solve attribute compatibility more easily. Moreover, because the top manager centralizes coordination in attribute matching, economies of scale are obtained. However, the coordination in attribute matching is harder to solve as the top manager has to rely on imperfect information about attribute shocks transmitted by local managers.

Beyond the above simple trade-off our model generates two sets of results regarding the dynamic effects of organizational forms in terms of the patterns of innovation and the performance of organizations. First, we show that the M-form is able to promote innovation not only through full-scale experimentation but also through small-scale experimentation, i.e. it can first experiment an innovation in some part of the organization before implementing it in the entire organization. In this sense the M-form has flexibility in experimentation. In contrast, the U-form only chooses to engage in full-scale experimentation. It thus lacks flexibility in experimentation. This difference between the two organizational forms relates to the nature of the two different types of coordination and the way the tasks are grouped. The reason why the M-form is capable of carrying out small-scale experimentation is that the complementary tasks are grouped in the same units so that attribute matching can be carried out by local managers. In contrast, in the U-form, the complementary tasks are grouped separately in different units and centralized attribute matching is carried out across units. We show that small-scale experimentation in the U-form is always dominated by full-scale experimentation because the former creates complications in attribute matching.

Second, we show that when innovations are more uncertain in the sense that they have a low probability of success, the M-form is more efficient than the U-form due to its flexibility. In the M-form, small-scale experimentation gives an option value of waiting to learn about the quality of the blueprint. This reduces the cost of experimentation. This allows the M-form to engage in innovation in cases where it is not beneficial to do so for the U-form. The option value of waiting decreases as the probability of success becomes higher and small-scale experimentation can then be dominated by full-scale experimentation because it delays experimentation in the rest of the organization. On the other hand, when innovations have a high probability of success, the U-form is more efficient than the M-form due to economies of scale made possible by greater specialization. We call this the specialization advantage of the U-form.

We present some evidence from industries in the U.S. in the twentieth century and from the centrally planned economies in China and the Soviet Union that is consistent with those results.

The notion of M-form and U-form organizations was pioneered by the influential work of Chandler and Williamson. Chandler (1962, 1977) documented the cases of large American corporations that replaced the U-form by the M-form in the first half of the 20th century. Later, Williamson (1975, 1985) theorized that the overload problem of the headquarters was the main problem with the U-form corporation. Following Chandler and Williamson, some formal studies on the M-form and the U-form organizations have been undertaken. For example, Aghion and Tirole (1995) analyzed how M-form and U-form organizations generate and solve the overload problem, and Maskin, Qian, and Xu (2000) provide an analysis of incentive problems in M-form and U-form organizations.

In order to focus on the coordination problem, our paper assumes away the incentive problem and takes the team theoretic approach. The literature on team theory includes, among others, the pioneering work of Marschak and Radner (1972), Weitzman (1974) on coordination using price and quantity, Crémer (1980) and Aoki (1986) on the optimal partition of workshops inside an organization, Bolton and Dewatripont (1994) on the firm as a communication network, Garicano (2000) on the organization of knowledge in production, in addition to the work by Milgrom and Roberts cited above.

Our paper also relates to the literature on reform strategies in the transition from socialism to capitalism. While the contrast between "big-bang" approach in Eastern Europe and Russia and the "experimental" approach in China has been well recognized in the literature (e.g., McMillan and Naughton, 1992; Dewatripont and Roland, 1995; Sachs and Woo, 2000), our paper goes one step further to investigate the deeper reasons of how the pre-reform organizational differences have led different countries to pursue different strategies.

The rest of the paper is organized as follows. Section 2 introduces the modeling of task coordination. Section 3 explores the basic tradeoff in carrying out full-scale experimenation in M-form and U-form. Section 4 focuses on the comparison between small-scale and full-scale experimentation and the evaluation of performances in both organizational forms. Section 5 generalizes the model to n products and m processes. Section 6 derives a set of conditions under which the M-form and the U-form are optimal organizational forms. Section 7 presents evidence consistent with the predictions of the model. Section 8 concludes.

2 Modelling Task Coordination

Consider an economy with the technology which can be fully described by four tasks: $1A$, $2A$, $1B$, and $2B$. Tasks $1A$ and $2A$ (similarly tasks $1B$ and $2B$) are complementary to each other, while tasks $1A$ and $1B$ (similarly tasks $2A$ and $2B$) are similar to each other. We denote $i = 1, 2$ and $r = A, B$. We can think of i as "process" or "function" and r as "product" or "region," and task ir corresponds to a task concerning process i in product r. Later in this paper we will consider the case of $i = 1, 2...m$ and $r = 1, 2, ...n$, which corresponds to m processes (or functions) and n products (or regions).

We introduce two types of coordination. The first and most important one involves "attribute matching" of the complementary tasks. For example, if $1A$ and $2A$ represent respectively the engine and body for a particular model of a car, attribute matching means the matching of the attributes of the engine and body for that model. Failure of attribute matching leads to drastic loss of production. The second type of coordination refers to the coordination of similar or substitutable tasks, which we call "attribute compatibility." For example, similar production processes may be used to produce two types of engines for different models, and the compatibility between the two processes may help reduce the costs of production. Similar tasks are often separable: if they are not produced on the same lines, problems on line $1A$ should not affect production on line $1B$. Failures in attribute compatibility thus should have less drastic effects on production than the failure on attribute matching in general.

We assume an infinite time horizon and a flow of ideas for experiments over time that have the potential to improve the output of the organization (but without changing the structure of the organization itself). Suppose that prior to any experiment, the existing technology generates status quo payoffs of $\frac{R}{2}$ in each period in product A and product B respectively. With the discount factor δ, the net present value of status quo payoffs for the entire organization is given by $\frac{R}{1-\delta}$. One successful experiment will raise the payoff from each product by $\frac{R}{2}$ in each period from the time the experiment is introduced. That is, with a total of i successful experiments in the past in both products, the net present value of payoffs will be $\frac{(1+i)R}{1-\delta}$. The model assumes that only one experiment can be carried out in each period, but there is no limit on the total number of experiments to be carried out, that is, experimentation can raise payoffs without bound. In Appendix 1, we consider an alternative model: instead of assuming a continuous flow of experiment programs available over time, we allow for only one experiment to be available. If this program is bad or not successfully implemented, the organization will revert back to the old way.

An experiment faces two potential problems. The first problem concerns the quality of its blueprint. A blueprint has an uncertain outcome: it can be "good" with probability p and "bad" with probability $1-p$. We assume that blueprints available over time are stochastically independent. Furthermore, if a blueprint turns out to be good, then it will apply equally well to two products. A good blueprint, together with correct coordination in implementation, raises the payoff from each product permanently by $\frac{R}{2}$ but a bad blueprint always reduces the payoff from each product by $\frac{R}{2}$ in every period from the time the reform is introduced.

The second problem concerns implementation, which involves both attribute matching and attribute compatibility. On the one hand, even if all attributes are matched perfectly *ex ante* in the blueprints and the blueprint is good, unforeseen attribute shocks occur in implementing the blueprint. Attributes must then be mutually adjusted to observed attribute shocks. In our model, it is possible that the manager who coordinates is not the manager who collects information about attribute shocks. In such a case, the coordinating manager relies on the message sent by the manager collecting information. The probability of each message being correct is λ. With $\lambda \leq 1$, information transmission is generally imperfect. Imperfect information transmission may arise from the fact that two managers have different idiosyncratic knowledge and different interpretations of the same message. They may speak different "languages", for example, engineering language differs from marketing language. 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. Such noises in information transmission are assumed to be independent across tasks as well as over time. In our model, imperfect information transmission is the source of failure in achieving attribute matching, which would lead to a drastic loss of output.

To focus on the coordination issue we assume that obtaining a blueprint is costless whereas implementing it is not. We assume that attribute matching requires a one time setup cost, which is normalized to C for

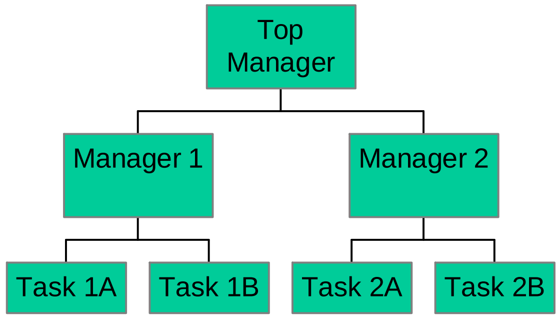

Figure 1: U-form Organizational Structure

two managers (and thus $\frac{C}{2}$ for each manager). This cost can be interpreted as a training cost or learning cost, that is managers need to be trained to implement a blueprint to learn how to match attributes. The following assumption ensures that the payoff increase from a good blueprint and good implementation is worth the setup cost:

Assumption 1 $\frac{R}{(1-\delta)} > C$.

We also assume that successful attribute matching for one product cannot be costlessly copied to another product because of product specific differences. If a blueprint tried in one product is found to be good and attribute matching is successful, although the same blueprint can be used for another product, separate coordination is still needed in order to adjust attributes to product specific conditions before a successful outcome can be achieved.

Failure to achieve attribute compatibility will also lead to a loss of output, although less drastically. For simplicity, we model attribute compatibility in a reduced form and use s $(0 < s \leq 1)$ to represent the reduced payoff due to the lack of attribute compatibility.

We define U-form and M-form organizations according to task assignment as follows. In a U-form organization, similar tasks are grouped together for the supervision by middle managers. Specifically, middle manager 1 is responsible for tasks $1A$ and $1B$ and middle manager 2 for tasks $2A$ and $2B$. Under the U-form, attribute compatibility is assured because manager 1 and manager 2 have the perfect information to do so. However, the two middle managers need to collect information about attribute shocks and send the information to the top manager, who then matches attributes between tasks $1A$ and $2A$ and between $1B$

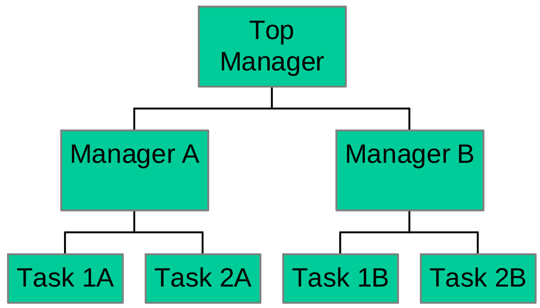

Figure 2: M-form Oranizational Structure

and $2B$. The U-form organization can be represented by Figure 1. It usually corresponds to the partitioning of the organization according to process or function.

In contrast, in an M-form organization, complementary tasks are grouped together for the supervision by middle managers. Specifically, middle manager A is responsible for tasks $1A$ and $2A$ and middle manager B for tasks $1B$ and $2B$. Because the two tasks which require attribute matching are assigned to the same manager, the middle managers can match attributes locally and perfectly. The top manager's job is to provide innovation blueprints, to decide the innovation strategy, and to ensure attribute compatibility, which is not assured due to the lack of information. The M-form organization can be represented by Figure 2. It usually corresponds to the partitioning of the organization according to product or region.

3 M-form vs. U-form: Full-Scale Experimentation

Under the status quo (i.e., no experimentation), the payoff in each period in both the M-form and the U-form is R, and thus the total payoff in terms of the net present value is given by $V^S = \frac{R}{1-\delta}$where δ is the discount factor. We now calculate the payoffs in the M-form and the U-form under the following strategy for experimentation: always start an experiment in both units of the organization in each period. We call this "full-scale experimentation". This strategy will be adopted if and only if its payoff is greater than the payoff from the status quo.

Consider first the U-form. Under the U-form, the two middle managers are responsible for coordinating attribute compatibility, which is thus always assured. The top manager is responsible for coordinating attribute matching. He receives four messages through noisy communication, each corresponding to one of the four tasks. To simplify the analysis, we assume that all signals for each function are perfectly correlated so that it is sufficient for a manager to communicate only one signal. When the program is bad, the experiment fails, and a new program will be tried in the next period. If the program is good, there are two possibilities due to the assumption of perfect correlation of signals: with probability λ^2, attribute matching is successful for both products A and B; with probability $\left(1-\lambda^2\right)$, attribute matching fails, which gives the same outcome as a bad program.

Because only the top manager matches attributes, whenever an experiment is introduced, a setup cost $\frac{C}{2}$ is paid under the U-form. We define stage i as the stage at which a total of i experiments have been successfully implemented. At stage i, the current period payoff for the two units without a new experiment is given by $(i+1)\,R$. Therefore, at stage i, with a successful new experiment, the current period payoff for the two units is given by $(i+2)\,R$. We obtain the recursive formula for the payoff at stage i in terms of the net present value V_i^{UF}:

$$V_i^{UF}=-\frac{C}{2}+p\{\lambda^2[(i+2)\,R+\delta V_{i+1}^{UF}]+\left(1-\lambda^2\right)\left(iR+\delta V_i^{UF}\right)\}+(1-p)\left(iR+\delta V_i^{UF}\right).$$

Let $a=\frac{1}{1-(1-\lambda^2 p)\delta}$. We have

$$\begin{aligned} V_i^{UF} &= a[-\frac{C}{2}+\lambda^2 p\,(i+2)\,R+\left(1-\lambda^2 p\right)iR+\lambda^2 p\delta V_{i+1}^{UF}] \\ &= -a\frac{C}{2}+2\lambda^2 paR+aRi+a\lambda^2 p\delta V_{i+1}^{UF}. \end{aligned}$$

From the above recursive formula, we calculate

$$V_o^{UF}=-a\frac{C}{2}\sum_{i=0}^{\infty}\left(a\lambda^2 p\delta\right)^i+2\lambda^2 paR\sum_{i=0}^{\infty}\left(a\lambda^2 p\delta\right)^i+aR\sum_{i=0}^{\infty}i\left(a\lambda^2 p\delta\right)^i,$$

where $V_o^{UF}$is finite because $a\lambda^2 p\delta=\frac{\lambda^2 p\delta}{1-(1-\lambda^2 p)\delta}<1$ for all $\delta<1$.

Using formulae $\sum_{i=1}^{\infty} ix^i=\frac{x}{(x-1)^2}$ and $\sum_{i=0}^{\infty} x^i=\frac{1}{1-x}$, and the fact that $\frac{a}{1-a\lambda^2 p\delta}=\frac{1}{1-\delta}$, we obtain the payoff at stage 0:

$$V_o^{UF}=-\frac{C}{2(1-\delta)}+\frac{p\lambda^2 R}{1-\delta}\left(2+\frac{\delta}{(1-\delta)}\right).$$

Consider now the M-form. Whenever an experiment program is introduced, setup costs $2(\frac{C}{2})=C$ must be incurred because two managers are involved in coordination. Because each unit manager is responsible for attribute matching, perfect attribute matching can always be achieved. However, attribute compatibility can be a problem since similar tasks are grouped separately in different units. We thus assume that with a new experiment, the current period payoff for the two units is given by $(i+1+s)\,R$, where sR represents the incremental payoff due to the new experiment and $s \leq 1$ is due to lack of attribute compatibility in the current period. To keep the analysis simple, we assume s is a deterministic parameter.

The payoff V_i^{MF} can then be written recursively as follows:

$$V_i^{MF} = -C + p[(i+1+s)R + \delta V_{i+1}^{MF}] + (1-p)\,[iR + \delta V_i^{MF}].$$

We can see that V_i^{MF} is similar to V_i^{UF}except that $\frac{C}{2}$ is replaced by C, λ^2 by 1 and we now have $i+1+s$ instead of $i+2$. We then analogously obtain:

$$V_o^{MF} = -\frac{C}{1-\delta} + \frac{pR}{1-\delta}\left((1+s) + \frac{\delta}{(1-\delta)}\right).$$

Because the status quo payoff is $V^S = \frac{R}{1-\delta}$, we define the critical value p^{MF} such that $V_o^{MF} = \frac{R}{1-\delta}$ and the critical value p^{UF} such that $V_o^{UF} = \frac{R}{1-\delta}$. This yields $p^{MF} = \frac{(R+C)(1-\delta)}{R[(1+s)(1-\delta)+\delta]}$ and $p^{UF} = \frac{(R+\frac{C}{2})(1-\delta)}{\lambda^2 R(2-\delta)}$.

Hence the M-form adopts a strategy of full-scale experimentation if and only if $p > p^{MF}$ and the U-form adopts the full-scale experimentation strategy if and only if $p > p^{UF}$. It is easy to obtain:

Proposition 1: *If $p^{MF} < p^{UF}$, which happens when communication quality λ is low, or compatibility s is high, or the setup cost C is low, then for all $p \in [p^{MF}, p^{UF}]$ the M-form chooses full-scale experimentation but the U-form does not and the M-form yields a higher payoff than the U-form. If $p^{MF} > p^{UF}$, the reverse is true.*

Proposition 1 illustrates the basic trade-off: the U-form has the advantage in specialization and attribute compatibility but suffers from the attribute matching problem, whereas the M-form achieves better attribute matching but suffers from the lack of attribute compatibility and less specialization. In particular, when communication quality is perfect $(\lambda = 1)$, then $p^{MF} > p^{UF}$ always holds and the U-form yields a higher payoff. Indeed, the U-form will experiment more because its gains from specialization reduce the costs of experimentation in the whole organization. On the other hand, when the setup cost is trivial $(C = 0)$ and attribute compatibility is not an issue $(s = 1)$, then $p^{MF} \leq p^{UF}$ always holds and the M-form will experiment more. In this case, the advantage from specialization plays no role and the U-form may suffer from the attribute matching problem. Proposition 1 follows quite directly from our assumptions but it formalizes some of the basic trade-offs identified in the organization literature.

4 M-form vs. U-form: Small-Scale and Full-Scale Experimentation

In this section we study the M-form and the U-form under small-scale experimentation strategies in comparison to the full-scale experimentation in the previous section. We first consider the small-scale experimentation strategy under the M-form: start an experiment in one of the two units and extend it to the other unit in the next period only if it is a success. We assume that a small-scale experiment causes attribute compatibility problems not only to the experimenting unit but also to the non-experimenting unit.[1]

Let V_i be the payoff in terms of the net present value at stage i. Let a new experiment program start in unit A but not in unit B at stage i. We call unit A the experimenting unit. The setup cost in the current period is $\frac{C}{2}$ because only unit A's manager coordinates. There are now two possibilities. If the program is good, the current period payoff is $\frac{(i+1+s)R}{2}$ in unit A and $\frac{(i+s)R}{2}$ in unit B. In the next period, the previous successful experiment program can be used in unit B after a setup cost $\frac{C}{2}$ is paid (because unit B's manager needs to match attributes) and unit A will try a new experiment program. If the program is bad, the current period payoff is $\frac{iR}{2}$ in the experimenting unit A and is $\frac{(i+s)R}{2}$ in the non-experimenting unit B. In the next period, a new experiment will again be introduced in unit A. We thus calculate the payoff under this strategy V_i^{MS} as follows:

$$V_i^{MS} = -\frac{C}{2} + p\left\{\frac{(i+1+s)R}{2} + \frac{(i+s)R}{2} - \delta\frac{C}{2} + \delta V_{i+1}^{MS}\right\} + (1-p)\left\{\frac{iR}{2} + \frac{(i+s)R}{2} + \delta V_i^{MS}\right\},$$

or let $a = \frac{1}{1-(1-p)\delta}$

$$\begin{aligned} V_i^{MS} &= -(1+p\delta)\frac{C}{2} + p\left(\frac{2+s}{2}R + iR + \delta V_{i+1}^{MS}\right) + (1-p)\left(\frac{sR}{2} + iR + \delta V_i^{MS}\right) \\ &= -(1+p\delta)\frac{C}{2} + (i+1)R + \frac{R}{2}(2p-2+s) + p\delta V_{i+1}^{MS} + (1-p)\delta V_i^{MS} \\ &= a\left(-(1+p\delta)\frac{C}{2} + (i+1)R + \frac{R}{2}(2p-(2-s))\right) + ap\delta V_{i+1}^{MS} \end{aligned}$$

Then we have

[1] An alternative assumption is that a small-scale experiment causes an attribute compatibility problem only to the experimenting unit, which causes less damage than under our above assumption. The results under the alternative assumption are qualitatively similar.

$$
\begin{aligned}
V_o^{MS} &= a\left(-(1+p\delta)\frac{C}{2}+\frac{R}{2}(2p-(2-s))\right)\sum_{i=0}^{\infty}(ap\delta)^i + aR\sum_{i=0}^{\infty}(i+1)(ap\delta)^i \\
&= \frac{1}{1-\delta}\left(-(1+p\delta)\frac{C}{2}+\frac{R}{2}(2p-(2-s))\right)+\left(\frac{p\delta R}{(1-\delta)^2}+\frac{R}{1-\delta}\right) \\
&= \frac{-(1+p\delta)C}{2(1-\delta)}+\frac{R}{1-\delta}\left(\frac{s}{2}+\frac{p}{1-\delta}\right).
\end{aligned}
$$

Hence we have

Proposition 2 *Under the M-form, the payoff difference between the small-scale and the full-scale experimentation strategy is given by* $V_o^{MS} - V_o^{MF} = \frac{1}{1-\delta}\left((1-p\delta)\frac{C}{2} + (\frac{1}{2}-p)Rs\right)$. *The relative advantage of the small-scale over the full-scale strategy is larger when* p *is smaller, or* C *is larger. The relative advantage is also larger when* s *is smaller if* $p > \frac{1}{2}$, *and when* s *is larger if* $p < \frac{1}{2}$.

The first term $\frac{(1-p\delta)C}{2(1-\delta)}$ indicates the option value of waiting to learn about the quality of the blueprint before sinking $\frac{C}{2}$ in the other unit of organization. This option value of waiting increases as p decreases. Therefore, small-scale experimentation can save on setup costs. This is reminiscent of the option value of early reversal of a bad blueprint in the case of many reforms tried out sequentially rather than together in a country (Dewatripont and Roland, 1995). The second term $\frac{(\frac{1}{2}-p)R}{1-\delta}$ is negative when $p > \frac{1}{2}$ and positive when $p < \frac{1}{2}$. When $p > \frac{1}{2}$, there is a cost of delaying experimentation in the non-experimenting unit B. This cost decreases as p decreases, and overall, the comparative advantage of small-scale experimentation increases as p decreases. Therefore, there is a trade-off between the option value of waiting and the cost of delaying the experiment in the other unit of the organization. In the extreme case when $p = 1$, we have $V_o^{MS} - V_o^{MF} = \frac{C}{2} - \frac{R}{2(1-\delta)}$ for $s = 1$, which is negative by Assumption 1. In other words, there is no advantage of small-scale experimentation. When $p < \frac{1}{2}$, then there is no cost from delaying the experiment in the non-experimenting unit B. On the contrary, experimenting would lead to a one period expected disruption because of the low probability of success. Then, there is no trade-off any more: small-scale experimentation yields both the option value of waiting and the gains from a smaller expected disruption (restricted to one unit) compared to large-scale experimentation. If $C = 0$, the first term vanishes and the second term alone determines the relative advantage of small-scale over full-scale strategy. It can go either way, depending on whether p is smaller or larger than $\frac{1}{2}$.

It is easy to calculate that $\frac{\partial}{\partial p}V_o^{MF} = \frac{R}{1-\delta}(1+s+\frac{1}{1-\delta})$ and $\frac{\partial}{\partial p}V_o^{MS} = \frac{1}{1-\delta}(\frac{R}{1-\delta} - \frac{\delta C}{2})$. We thus have $\frac{\partial}{\partial p}V_o^{MF} > \frac{\partial}{\partial p}V_o^{MS}$. By Assumption 1, we must also have $\frac{\partial}{\partial p}V_o^{MS} > 0$. We define p^* such that V_o^{MF}

$= V_o^{MS}$, that is $(1-p^*\delta)\frac{C}{2} = (p^* - \frac{1}{2})Rs$, from which we solve for $p^* = \frac{C+Rs}{\delta C+2Rs}$. Hence we always have $p^* > \frac{1}{2}$. Therefore, the small-scale experimentation strategy yields a higher payoff than the full-scale experimentation strategy (i.e., $V_o^{MS} > V_o^{MF}$) if and only if $p < p^*$.

Now we define the critical value p^{MS} such that $V_o^{MS} = V^S = \frac{R}{1-\delta}$, where $\frac{R}{1-\delta}$ is the status quo payoff. We derive that $p^{MS} = \frac{((2-s)R+C)(1-\delta)}{2R-\delta(1-\delta)C}$

Under the M-form, the organization has three possible strategies: the status quo, small-scale experimentation and full-scale experimentation. Therefore, the overall payoff under the M-form is given by

$$\begin{aligned} V_o^M &= \max\left\{V^S, V_o^{MS}, V_o^{MF}\right\} \\ &= \max\left\{\frac{R}{1-\delta}, -\frac{(1+p\delta)\,C}{2(1-\delta)} + \frac{R}{1-\delta}\left(\frac{s}{2}+\frac{p}{1-\delta}\right), -\frac{C}{1-\delta} + \frac{pR}{1-\delta}\left((1+s)+\frac{\delta}{(1-\delta)}\right)\right\}. \end{aligned}$$

Proposition 3 *Under the M-form, the small-scale experimentation strategy yields a higher payoff than the full-scale experimentation strategy if and only if $p < p^*$. Furthermore, the small-scale experimentation strategy yields a higher payoff than the status quo while the full-scale experimentation strategy yields a lower payoff than the status quo if and only if $p \in \left(p^{MS}, p^{MF}\right)$.*

Proof From Assumption 1 we can easily derive $p^{MS} < p^{MF} < p^*$. Q.E.D.

Proposition 3 shows that the advantage of small-scale experimentation is present for low levels of p. Moreover, even when the likelihood of success is sufficiently low that a large-scale experimentation yields lower payoffs than the status quo, small-scale experimentation can still be profitable because it reduces the downside of experimentation. This result shows that the option of small-scale experimentation under the M-form is valuable for low values of p (though not necessarily lower than $\frac{1}{2}$).

We now consider possible small-scale experimentation strategies under the U-form where change is done first in one unit and, if successful, implemented in both units the next period. Assume thus that small-scale experimentation involves adopting an experiment for tasks $1A$ and $1B$ in unit 1, and if successful, in the next period it is extended to tasks $2A$ and $2B$ in unit 2. Again, attribute compatibility is assured. This kind of experimentation is more difficult to imagine in the real world. Our model will indeed predict (Proposition 4 below) that we should not see such type of experimentation since it is always dominated by large-scale experimentation.[2]

[2] To illustrate this in an easy way, think of changes in computer softwares including an operating system and applications.

We assume that the quality of the program (good or bad) can be discovered even when the experiment 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.

We can write the recursive formula for the payoff at stage i in terms of the net present value V_i^{US}:

$$V_i^{US} = -\frac{C}{2} + p\lambda^2\{(i+1+\frac{1}{2})R + \delta[-\frac{C}{2} + \lambda^2(i+2)R + (1-\lambda^2)iR + \delta V_{i+1}^{US}]\} + \left(1-p\lambda^2\right)\left(iR + \delta V_i^{US})\right\},$$

from which we derive

$$V_0^{US} = -\frac{C}{2(1-\delta)} + \frac{p\lambda^2 R}{(1-\delta)(1+p\lambda^2 R)}\left(\frac{3}{2} + 2\lambda^2\delta + \frac{\delta^2}{1-\delta}\right).$$

We want to compare this with $V_o^{UF} = -\frac{C}{2(1-\delta)} + \frac{p\lambda^2 R}{1-\delta}\left(2 + \frac{\delta}{(1-\delta)}\right)$.

Note that the experimentation strategy does not save in set-up costs, and V_0^{US} and V_0^{UF} differ only in their expected benefits. However, comparing both expressions for expected benefits is not trivial. We do the comparison by first constructing an alternative strategy of full-scale experimentation $\widetilde{UF}$ in which after a success with a new experiment, the organization will keep that program for an additional period and try a new program only one period later. Otherwise, the strategy is the same as in the original full-scale experimentation strategy. We label the payoffs from this strategy $V_0^{\widetilde{UF}}$. This strategy is constructed to be inferior to UF . We show below that it dominates US and therefore UF must dominate US.

Proposition 4 *Under the U-form, the small-scale experimentation strategy always yields lower payoffs than the full-scale experimentation strategy (i.e., $V_0^{UF} > V_0^{US}$ whenever $V_0^{US} > V^S$).*

Proof First we show that the constructed strategy $V_0^{\widetilde{UF}} > V_0^{US}$ for all parameters. We can write the recursive formula for the payoff at stage i in terms of the net present value $V_0^{\widetilde{UF}}$:

$$V_0^{\widetilde{UF}} = -\frac{C}{2} + p\lambda^2\{(i+2)R + \delta[(i+2)R + \delta V_{i+1}^{\widetilde{UF}}]\} + \left(1-p\lambda^2\right)\left(iR + \delta V_i^{\widetilde{UF}}\right),$$

Here task 1 represents changes in the operating system and task 2 represents changes in the word processor. Small-scale experimentation under this strategy means, for example, first changing the operating system (say from DOS to Windows), and then changing the word processor (from WordPerfect 5.1 to WordPerfect 6). Coordination 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.

from which we calculate the value of $V_0^{\widetilde{UF}}$ as follows:

$$V_0^{\widetilde{UF}} = -\frac{C}{2(1-\delta)(1+p\lambda^2 R)} + \frac{p\lambda^2 R}{(1-\delta)(1+p\lambda^2 R)}\left(2(1+\delta) + \frac{\delta^2}{1-\delta}\right).$$

We get that $V_0^{US} - V_0^{\widetilde{UF}} = -\frac{p\lambda^2 R}{(1-\delta)(1+p\lambda^2 R)}\left(\frac{C+1}{2} + 2(1-\lambda^2)\delta\right) < 0.$

We now verify that $V_0^{UF} > V_0^{\widetilde{UF}}$ whenever $V_0^{\widetilde{UF}} > V^S$. The condition for $V_0^{\widetilde{UF}} > V^S$ is given by

$$V_0^{\widetilde{UF}} = -\frac{C}{2(1-\delta)(1+p\lambda^2 R)} + \frac{p\lambda^2 R}{(1-\delta)(1+p\lambda^2 R)}\left(2(1+\delta) + \frac{\delta^2}{1-\delta}\right) > \frac{R}{1-\delta},$$

which is equivalent to $p > \frac{(\frac{C}{2}+R)(1-\delta)}{\lambda^2 R(1+\delta-\delta^2)}$.We calculate that $V_o^{UF} > V_0^{\widetilde{UF}}$ if and only if

$$-\frac{C}{2(1-\delta)} + \frac{p\lambda^2 R}{1-\delta}\left(2 + \frac{\delta}{(1-\delta)}\right) > -\frac{C}{2(1-\delta)(1+p\lambda^2 R)} + \frac{p\lambda^2 R}{(1-\delta)(1+p\lambda^2 R)}\left(2(1+\delta) + \frac{\delta^2}{1-\delta}\right),$$

and if and only if $p > \frac{(\frac{C}{2}+R)(1-\delta)}{\lambda^2 R(2-\delta)}$.Because $\frac{1}{(1+\delta-\delta^2)} > \frac{1}{(2-\delta)}$, then whenever $V_0^{\widetilde{UF}} > V^S$, we must have $V_0^{UF} > V_0^{\widetilde{UF}}$.

Let $V_0^{US} > V^S$. We have shown above that $V_0^{\widetilde{UF}} > V_0^{US}$. We have also shown that $V_0^{UF} > V_0^{\widetilde{UF}}$. Therefore, we have $V_0^{UF} > V_0^{\widetilde{UF}} > V_0^{US}$. Q.E.D.

Proposition 4 states that, contrary to the M-form, the U-form organization does not benefit from the small-scale experimentation strategy. What are the reasons for this? First, there is no economy in saving expected setup costs as in the M-form. Indeed, the setup cost is not lower than under full-scale experimentation. Second, separately and more importantly, there are complications in coordinating activities and some of these complications are present even when $\lambda = 1$, i.e. when communication is perfect. The proof of proposition 4 gives us a good intuition for why. We showed first that the small-scale experimentation strategy was dominated by a full-scale experimentation strategy $\widetilde{UF}$ whereby one would wait one period before trying a new experiment. To see why this is the case, it is useful to compare term by term the recursive formulas for V_0^{US} and $V_0^{\widetilde{UF}}$ derived above. We see that the small-scale experimentation strategy 1) has a smaller first period benefit in case of a successful experiment, 2) has to incur an additional setup cost for the second stage of attribute matching, and 3) has to suffer losses from imperfect communication due to the need for attribute matching in the second round. All the three factors point to the disadvantage of V_0^{US} relative to $V_0^{\widetilde{UF}}$. In addition, by construction, $\widetilde{UF}$ is dominated by UF because in the former when an experiment is successful it takes two periods rather than one before trying out a new one. Therefore, the U-form is less flexible in terms of small scale experimentation.

Note that small-scale experimentation is dominated by the full-scale experimentation in the U-form for all values of p whereas in the M-form it is dominated only for high values of p. The reason is that under small-scale experimentation the M-form has a smaller payoff in case of success, relative to full-scale experimentation, but a higher one in case of failure, because the status quo payoff is maintained in the non-experimenting unit. In the U-form, however, there is similarly a lower payoff in case of success but no advantage in case of failure. This is because the status quo payoff cannot be maintained in the unit where the old attributes are kept.

The fundamental reason that small-scale experiment is always dominated by full-scale experiment under the U-form is the complications in attribute matching under the U-form, which in turn is related to the way the tasks are grouped under the U-form: the complementry tasks are grouped separately in different units and attribute matching must be solved across units. Under small-scale experimentation, it is necessary for the U-form to coordinate in two steps: the first step between the new tasks in unit 1 and the old tasks in unit 2 and the second step between the new tasks in units 1 and 2. In contrast, under the M-form, the complementary tasks are grouped in the same units. At the time a successful experiment in unit A is replicated in unit B, unit A can already start a next experiment. Although coordination failure in attribute compatibility causes some losses in scale economy or positive externalities, it does not lead to drastic consequences as in coordination failure in attribute matching. This asymmetry in coordination of attribute matching and attribute compatibility explains the different results concerning small-scale experimentation in the M-form and the U-form.

In the above discussion of small-scale experimentation we have compared the M-form and U-form organizations where *one unit* within the organization experiments. What about a small-scale experiment *across units*? One could imagine, for example, the U-form replicating M-form style experimentation by implementing an experiment between task $1A$ in unit 1 and task $2A$ in unit 2. For the sake of completeness, we develop this case in Appendix 2. The result there shows that on the one hand, contrary to the M-form and like the case with the U-form, there is no option value of waiting from small-scale experimentation. This means that the option value of waiting advantage of small-scale experimentation is unique to the M-form. On the other hand, like the M-form, small-scale experimentation can dominate large-scale experimentation when p and λ are small. However, we think that this type of cross-unit experimentation is less realistic. One can think of at least two important reasons for why this may be the case. First, if the U-form has the advantage of specialization and absence of duplication, it is reasonable to think that there are technological indivisibilities involved between tasks $1A$ and $1B$ so that for example the same production line or equipment is used for both tasks. We have not modelled explicitly such indivisibilities but one can argue that such indivisibilities are a reason for a specialization advantage and thus for lower operating costs in the U-form. A second and probably more important reason is related to the limited attention of management. If we assume that 1) in the absence of innovation, management must pay attention to current operations, and 2) attribute matching in the event of innovation requires full attention of management, and 3) attribute matching on a larger scale requires the same attention as on a smaller scale, then if half of each unit in the U-form is experimenting while the other half is not, the top management will have an overload problem. This is because he would focus on attribute matching in half of each unit and at the same time pay attention to current operation in the other half, which might be too much given that his attention is limited. Note that this limited attention argument is very close to Williamson's argument about overload in the U-form (Aghion and Tirole, 1995 also studied the overload problem in a model of incentives in organizations).

When small-scale experimentation is ruled out under the U-form, as a consequence of Proposition 4, the organization has only two possible strategies: the status quo and the full-scale experimenation strategy. The overall payoff under the U-form is given by

$$\begin{aligned} V_o^U &= \max\left\{V^S, V_o^{UF}\right\} \\ &= \max\left\{\frac{R}{1-\delta}, -\frac{C}{2(1-\delta)} + \frac{p\lambda^2 R}{1-\delta}\left(2 + \frac{\delta}{(1-\delta)}\right)\right\}. \end{aligned}$$

We define $\widetilde{p}$ such that $V_o^{UF} = V_o^{MS}$ for $\lambda = 1$, that is,

$$-\frac{C}{2(1-\delta)} + \frac{\widetilde{p}R}{1-\delta}\left(2 + \frac{\delta}{(1-\delta)}\right) = -\frac{(1+\widetilde{p}\delta)\,C}{2(1-\delta)} + \frac{R}{1-\delta}\left(\frac{s}{2} + \frac{\widetilde{p}}{1-\delta}\right),$$

from which we solve for $\widetilde{p} = \frac{Rs}{2R+\delta C}$. Therefore, we must have $\widetilde{p} < \frac{1}{2} < p^*$.

We are now ready to compare the M-form and the U-form when all possible experimentation strategies are allowed. When $C = 0$, clearly the M-form under full-scale experimentation already has higher payoffs than the U-form simply because the former avoids the cost disadvantage. With the possibility of small-scale experimentation strategy, the M-form can do even better for $p < \frac{1}{2}$. In the following dicussion we assume $C > 0$. First, consider the case when the communication quality λ is low. From Proposition 1, we learned that if we restrict the experimenting strategy to full-scale experimentation, then the M-form has an advantage over the U-form. With the possibility of small-scale experimentation, the advantage of the M-form over the U-form can only be further strengthened. This is because by Proposition 3, the M-form with small-scale experimentation strategy can do better than full-scale experimentation for $p \in \left(p^{MS}, p^{MF}\right)$.

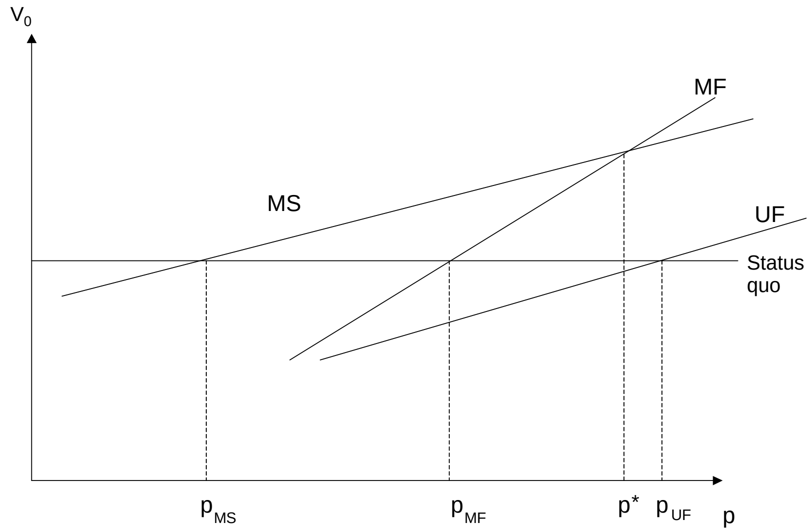

Figure 3: Experiment strategy comparison when λ is low.

At the same time, by Proposition 4, small-scale experimentation does not help the U-form at all. Figure 3 illustrates this case of low λ, where the slope of V_o^{UF} is flatter than that of V_o^{MF}. The advantage of the M-form is related to better communication within the organization.

Next consider the case when communication quality λ is high. Proposition 1, restricted to full-scale experimentation showed that the U-form has an advantage over the M-form. But with the introduction of the possibility of small-scale experimentation, even in the case when λ is high, the M-form will still have an advantage over the U-form in using small-scale experimentation if p is relatively low:

Proposition 5 *Assume $C > 0$. When the quality of communication λ is high, provided δ is large, the M-form (with the optimal strategy of small-scale experimentation) yields a higher payoff than the U-form (with the optimal strategy of full-scale experimentation) for all $p \in [p^{MS}, \widetilde{p}]$. The reverse is true for all $p \in [\widetilde{p}, 1]$.*

Proof Proposition 4 showed that the dominant strategy under the U-form is full-scale experimentation. Note also that when λ is close to $1, V_o^{UF} \geq V_o^{MF}$ with strict inequality for $C > 0$. Indeed, an inspection of the expressions for V_o^{UF} and V_o^{MF}shows that the expected benefits are the same while the expected costs are lower for V_o^{UF}. All we need to do is thus to compare V_o^{MS} and V_o^{UF}. We first see that $p^{MS} < \widetilde{p}$ when δ approaches 1. Moreover, we find that when λ is close to 1, $\frac{\partial V_o^{MS}}{\partial p} = \frac{1}{1-\delta}(\frac{R}{1-\delta} - \frac{\delta C}{2}) < \frac{R}{1-\delta}(2 + \frac{\delta}{1-\delta}) = \frac{\partial V_o^{UF}}{\partial p}$.

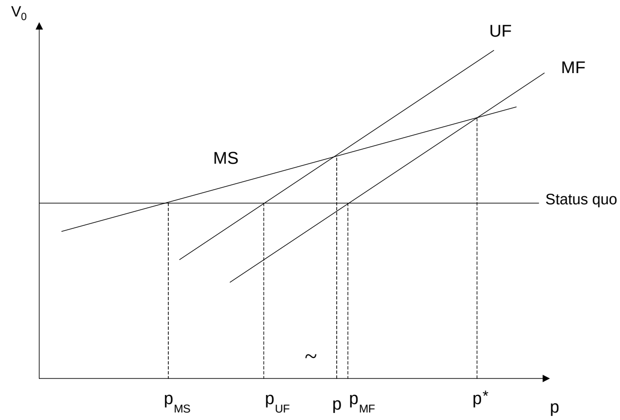

Figure 4: Experiment strategy comparison when λ is high

By definition of $\widetilde{p}$ and because of the higher slope of $\frac{\partial V_o^{UF}}{\partial p}$, we thus conclude that for all $p \in [p^{MS}, \widetilde{p}]$, $V_o^{MS} > V_o^{UF}$ and the reverse is true for all $p \in [\widetilde{p}, 1]$. Q.E.D.

Figure 3 illustrates this case of high λ where the slope of V_o^{UF} is very close to that of V_o^{MF} when s is close to 1. Proposition 5 is interesting because it shows that the M-form can do better than the U-form even when communication quality is very high in the U-form, i.e. when λ approaches 1. This is because the flexibility of the M-form in terms of small-scale experimentation allows it to experiment even when p is small. Although the U-form has an advantage of specialization to avoid the duplication of setup costs, it does not have the flexibility of carrying out experiments in only part of the organization. The fundamental reason why the M-form has that flexibility is precisely its organizational duplication: each unit is self contained and coordination is carried out locally by more than one manager. While economists traditionally tend to emphasize the importance of specialization for efficiency, there is the other side of the coin: specialization may create rigidity which can be bad for experimentation. The M-form can thus do better due to its flexibility in experimentation in self-contained units which is an advantage when p is low. Otherwise, for higher values of p, the U-form still can do better because of its advantage in specialization.

5 Generalization

We now generalize the above model to n products and m processes. We normalize the setup cost of implementing an experiment under the M-form to C and that under the U-form to $\frac{C}{n}$. The status quo payoff of the entire organization is $\frac{R}{1-\delta}$ (or equivalently $\frac{R}{n(1-\delta)}$ in each product). We assume away attribute compatibility problem so that $s=1$ for simplicity.

Consider the M-form first. The organization has n units along product lines. Within each unit, a middle level manager is responsible for coordinating m tasks within the product and perfect coordination is always achieved. Let α be the fraction of experimenting units where $\alpha \in \left[\frac{1}{n}, 1\right]$.

The net present value payoff in stage i under the M-form:

$$V_i = -\alpha C + p\left\{(i+1)R + \alpha R - \delta(1-\alpha)C + \delta V_{i+1}\right\} + (1-p)\left\{(i+1)R - \alpha R + \delta V_i\right\}.$$

Recall that $a = \frac{1}{1-(1-p)\delta}$. We then obtain:

$$\begin{aligned} V_o^{M_\alpha} &= a[-(\alpha + p\delta(1-\alpha))C + \alpha R(2p-1)]\sum_{i=0}^{\infty}(ap\delta)^i + aR\sum_{i=0}^{\infty}(i+1)(ap\delta)^i. \\ &= -\frac{\alpha + (1-\alpha)p\delta}{1-\delta}C + \frac{R}{1-\delta}\left(\alpha(2p-1) + 1 + \frac{p\delta}{1-\delta}\right) \end{aligned}$$

Let $p^* = \frac{C+R}{C\delta+2R}$. Under Assumption 1, $p^* < 1$. Therefore, we have the following result, which is parallel to the first part of Proposition 3:

Proposition 6 *When an experimentation strategy is preferred to the status quo, the M-form's optimal strategy is full-scale experimentation strategy if $p > p^*$ and the small-scale experimentation strategy to experiment in just one product if $p < p^*$.*

Proof Note that $V_o^{M_\alpha}$ is linear in α, and $\frac{\partial}{\partial\alpha}V_o^{M_\alpha} = -\frac{1-p\delta}{1-\delta}C + \frac{R}{1-\delta}(2p-1)$. At $p = p^*$, $\frac{\partial}{\partial\alpha}V_o^{M_\alpha} = 0$. For $p > p^*, V_o^{M_\alpha}$ is an increasing function in α, therefore the optimal α is 1. For $p < p^*, V_o^{M_\alpha}$ is a decreasing function in α, therefore the optimal α is $\frac{1}{n}$. Q.E.D.

Therefore, the payoff under the M-form is given by

$$\begin{aligned} V_o^M &= \begin{cases} \max\left\{V^S, V_o^{M_\alpha}\right\} \text{ where } \alpha = 1, \text{ for } p \geq p^* \\ \max\left\{V^S, V_o^{M_\alpha}\right\} \text{ where } \alpha = \frac{1}{n}, \text{for } p < p^* \end{cases} \\ &= \begin{cases} \max\{\frac{R}{1-\delta}, -\frac{C}{1-\delta} + \frac{pR}{1-\delta}\left(2 + \frac{\delta}{1-\delta}\right)\}, \text{ for } p \geq p^* \\ \max\{\frac{R}{1-\delta}, -\frac{C}{1-\delta}(\frac{1+(n-1)p\delta}{n}) + \frac{R}{1-\delta}\left(\frac{2p+n-1}{n} + \frac{p\delta}{1-\delta}\right)\}, \text{ for } p < p^* \end{cases}. \end{aligned}$$

Because V_o^M is not a function of m, any change in m has no effect in the M-form. Consider the situation where the status quo is dominated by experimentation. When $p > p^*$, the optimal $\alpha = 1$, a change in n has no effect on in the M-form. When $p < p^*$. Then the optimal $\alpha = \frac{1}{n}$, and $\frac{\partial V_o^M}{\partial n} = \frac{1}{(1-\delta)n^2}\left(R + C - p\left(C\delta + 2R\right)\right)$, so an increase in n has a positive effect in the M-form.

In the U-form, the organization has m units along process lines. Within each unit, a middle level manager is responsible for collecting information about attribute shocks and sending a message to the top manager. The top manager receives correct information with probability λ^m and coordinates m tasks for all n products. In the U-form organization, with full-scale experimentation, the payoff in stage i is given by:

$$\begin{aligned} V_o^U &= -\frac{C}{n} + p\{\lambda^m[(i+2)\,R + \delta V_{i+1}] + (1-\lambda^m)\,(iR + \delta V_i)\} + (1-p)\,(iR + \delta V_i)\,. \\ &= -\frac{C}{n(1-\delta)} + \frac{p\lambda^m R}{1-\delta}\left(2 + \frac{\delta}{(1-\delta)}\right) \end{aligned}$$

It is easy to see that in the U-form, an increase in the number of processes m has a negative effect and an increase in the number of products n has a positive effect, independently of the value of p and λ.

Because $\frac{\partial V_o^U}{\partial n} = \frac{C}{(1-\delta)n^2}$, a simple comparison of $\frac{\partial}{\partial n}V_o^{UF}$ and $\frac{\partial}{\partial n}V_o^M$ demonstrates that for $p < p^*$ an increase in the number of products n has a larger positive effect in the U-form than in the M-form if and only if $p > \widetilde{p}$.

6 Conditions for the Optimality of M-Form and U-Form

In this section, we provide a set of conditions under which the M-form and the U-form dominate other organizational forms so that our focus on these two forms can be justified. We restrict our attention to the case of two products and two processes only, but the underlying principle is general.

Figure 5 illustrates possible types of organizational forms in the case of two products and two processes. Figures 5(a) and 5(b) are the U-form and the M-form respectively. Figure 5(c) is the flat organizational form in which all coordination is done by one manager. Figures 5(d) and 5(e) are skewed organizational forms where one middle manager coordinates two or three tasks and the top manager coordinates the residual task(s). Figure 5(f) is a symmetric form but represents a different partition of tasks than the M-form or U-form. Figure 5(g) is a stand alone organizational form without middle managers. Other alternatives not present in Figure 5 are cases where one manager is responsible for one task only. With more than two products and two processes there are more possibilities but the two by two case serves as a good illustration.

We assume that in an organization there are the following distinct types of knowledge: knowledge on process and kowledge on products related to identifying/describing attribute shocks; and knowledge on blueprints related to strategic decisions (selection of blueprints). We further assume that each manager can aquire only one type of knowledge. This is because the capacity of human beings to aquire knowledge is limited and the character of knowledge is specialized. Formally, we make the following assumption about the knowledge of a manager:

Assumption K *A manager's knowledge is limited to one of the following:*

(K1) process for any given product;

(K2) product for any given process;

(K3) blueprints.

Moreover, we suppose that as long as information on attribute shocks is known coordinating-task per se does not rely on knowledge (K1), (K2) and (K3).

We first demonstrate that both the M-form and U-form satisfy Assumption K. Under the M-form, the top manager engages in strategic decisions, which requires knowledge (K3). Each of the two middle managers engages in collecting attribute shock information and coordinates tasks accordingly in his own units. The information collection and task coordination within a unit require knowledge (K1). Therefore, Assumption K is satisfied. Under the U-form, each of the two middle managers is responsible for one of the two processes respectively; and each of them collects information on attribute shocks associated with that process in the two products requiring knowledge (K2); and transmits the information to the top manager. The top manager then coordinates, which does not rely on knowledge (K1) or (K2). Moreover, the top manager takes up strategic decisions requiring knowledge (K3). Again, Assumption K is satisfied. In both of these organizational forms, the number of managers hired for the entire organization is 3.

Because any organization requires all three types of knowledges to run, Assumption K rules out any organizational form employing fewer than 3 managers. Organizational forms (c), (d), (e) and (g) all employ 1 or 2 managers and thus violate Assumption K.

Among all organizational forms employing 3 managers the M-form and the U-form organizations are the only ones that satisfy Assumption K. In the organizational form (f) in Figure 5, one manager is responsible for tasks 1A and 2B, and the other for tasks 1B and 2A. This would imply that each of them must have both knowledge (K1) and (K2), a violation of Assumption K.

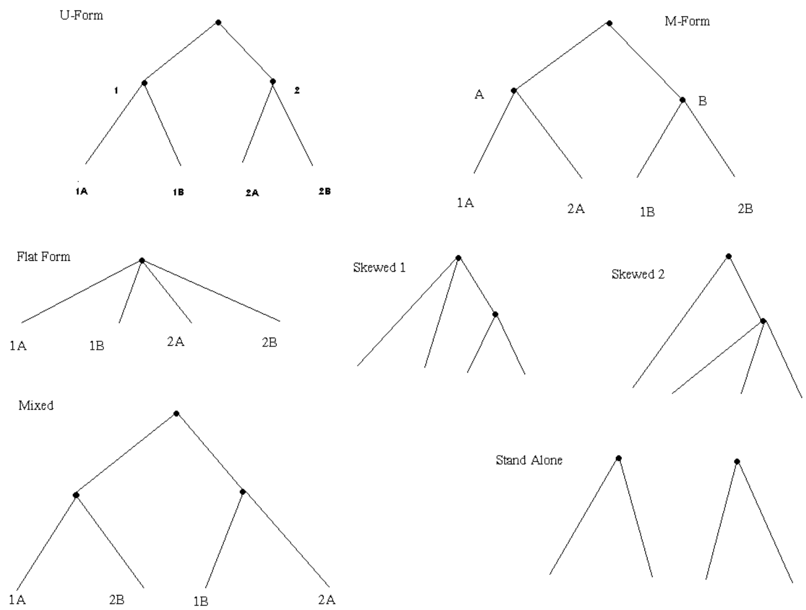

Figure 5: General Oranizational Forms

Therefore, all the organizational forms satisfying Assumption K other than the M-form and the U-form must hire more than 3 managers. If we assume that hiring additional managers entails additional costs, then an organizational form that employs more than 3 managers does not have a cost advantage over an organizational form that employs only 3 managers. When this cost is sufficiently high, it rules out an organizational form such as for example 4 managers each responsible for collecting information on one region and one function only and an additional manager for strategic decisions.

To conclude, under Assumption K and assuming costly managers, the M-form and the U-form are the only optimal organizational forms. A more complete analysis of the optimality of different organizational forms deriving from primitive assumptions is beyond the scope of this paper but is an important avenue for further research.

7 Evidence

Our model has two major predictions related to the probability of success p and organizational forms. First, Proposition 5 makes a prediction on the relative efficiency of the two organizational forms in innovation: when the probability of success p is low, the M-form is more efficient due to its flexibility in small and full scale experimentation; when p is high, the U-form is more efficient due to its specialization advantage. Second, Propositions 3 and 4 spell out predictions on the experimentation strategies of the two organizational forms: the M-form conducts small-scale experiments when p is low and conducts full-scale experiments otherwise, whereas the U-form only conducts full-scale experiment if conducting experiments at all.

We first provide two pieces of evidence on the first prediction. In the market economy, more efficient organizational forms in firms are observed as a result of competition. In the 20th century, innovations in the metal industry and in the railroad industry were mostly incremental. For example, markets for metal products were more standardized and there was less change since most customers were firms rather than households (they had "relatively few large customers [...] (and) manufactured many standardized products" (p.327, Chandler, 1962)). By contrast, the automotive industry and the chemical industry have faced drastic innovations, with revolutionary new products, expanding new markets, and new consumer goods. In terms of our model, one can argue that the metal industry faced incremental innovations with relatively low uncertainty and a relatively high probability of success p. In contrast, the automotive industry and chemical industry were experimenting with more bold innovations under higher conditions of uncertainty and thus one can reasonably argue that they faced a lower p. The model predicts that we should observe more U-form firms in the metal industry but more M-form firms in the car and chemical industries. Indeed, Chandler (1962, 1977) documents that the M-form has become the dominant organizational form in large U.S. corporations both in the car industry (e.g. GM) and the chemical industry (e.g. Du Pont), while the sectors that did not introduce the M-form were concentrated in the metal industries. For example, the copper and nickel companies have kept their functionally departmentalized structures, and the steel companies even increased centralization over time. In the steel industry, five out of eight large steel makers in the U.S. have kept the U-form structure. In the other three companies (Armco, National Steel, US Steel), there was a trend to move to the U-form. US Steel, the largest steel maker in the U.S. was reorganized into a functionally departmentalized structure in 1950. "All activities administered by Central Operations were departmentalized along functional lines. A single set of Executive Vice Presidents became ... responsible for the administration of their different functions in every part of the corporation" (Chandler, pp. 334-335, 1962). Such Executive Vice-presidents were responsible for Production, Sales, and Engineering respectively. Under each of the Executive Vice Presidents, there were Vice Presidents responsible for further specialized functions. For example, under the Executive Vice President for Sales, there were Vice Presidents for Sales, Warehousing-organization, etc. respectively.

Our next example concerns the comparison of two centrally planned economies: the Soviet Union and China. The structure of the Soviet economy as a whole is similar to a U-form corporation along functional lines. At the top was the Gosplan. Under this central authority there were seven industrial complexes, each in turn supervising several ministries specializing in one particular industry. Therefore the Soviet economy can be viewed as a gigantic U-form coordinating specialized production in the whole economy. Indeed, the Gosplan was responsible for about 12 million planning indicators (Nove, 1980). The U-form organization was also replicated at the level of individual ministries: ministries were organized in functional departments overseeing extremely specialized production units. In contrast to the Soviet Union, central planning in China was organized mainly along territorial lines. Regional governments were responsible for the whole array of production in their region. Typically, the production of each region was diversified and relatively self-contained (Granick, 1990; Qian and Xu, 1993). Therefore, the Chinese economy can be viewed as one gigantic M-form where each region resembles a division in an M-form corporation. With regional governments taking major responsibilities for coordinating tasks across industries, the central government's role in coordination was greatly reduced. Indeed the number of planning indicators for which the State Planning Commission at the Chinese central government was responsible never exceeded 1,000 (Qian and Xu, 1993).

The performance of the metallurgy industry in these two economies is consistent with the prediction of our model as well. Indeed, the model predicts that when p is high enough, the U-form will perform better than the M-form due to its advantages in specialization. The metallurgy industry in the Soviet economy was organized in functionalized ministries each specialized in one type of metal, such as iron and steel, other ferrous metals, or non-ferrous metals. The whole steel industry was coordinated by the Ministry of Iron and Steel and the organizational structure of the ministry was very similar to those of large steel companies in the United States, such as that of the US Steel. Under the ministry, tasks were further divided in functionalized departments, such as Production Department, Special Steel Department, Mining Department, Coke Department etc., and these departments supervised specialized enterprises. (Clark, 1956). Moreover, there had been a trend toward further specialization in the industry after World War II (Bannei, 1984).The Soviet U-form of central planning was conducive to quite extraordinary growth in the metallurgy industry. In fact, Soviet steel output increased at one of the highest speeds in the world and, starting from a moderate level, achieved the highest level in the world in a short period of time. It increased from 14.5 million tons in 1947 to 102 million tons in 1967 in twenty years; and further increased to 147 million tons in 1977 (Pockney, 1991). In China, specialization in metallurgy was less developed. There was only one ministry, the Ministry of Metallurgy Industry, to take care of the tasks that were handled by several ministries in the Soviet Union. Except for few large steel firms which were under the control of both this Ministry and regional governments, most steel firms were medium sized (each producing less than 1 million ton annually) and under the control of regional governments. The industry was not specialized even at the provincial level and larger steel companies were self-contained as a rule. The Chinese M-form of central planning did not fare well in metallurgy. Starting from an output level comparable to that of the Soviet Union in 1947, the Chinese achieved only half of what the Soviet Union achieved within the same length of time: steel output increased from 13.3 million tons in 1969 to 61.6 million tons in 1989 (National Statistical Bureau, 1983 and 1990). This poor performance is not easily explained by other factors. For example, it is well documented that the Chinese government has put the highest priority on the development of the steel industry since the 1950s. Moreover, there is no evidence of lack of resources. In fact, China has the world's largest coal reserves and fairly large iron ore reserves. Until the mid 1990s the Chinese iron ore production grew above 10% annually and the proportion of imported iron ore in total iron ore comsumption was marginal.

The evidence from the US and from centrally planned economies is complementary. Competition in a market economy drives firms to adopt organizational forms that improve efficiency. In metallurgy, this was the case of the U-form. The comparison between the Soviet Union and China where the organizational form was fixed under central planning confirms the higher efficiency of the U-form in metallurgy industry in the Soviet Union.

We next provide some evidence on the second prediction. We compare the features of agricultural reforms in the Soviet Union and China. Agricultural reforms in both countries were centered on land reform to replace collective farming by household farming. Whereas technological innovation in agriculture is likely to feature a relatively high p, things are different with economic reform in agriculture. Although household farming is a common practice in market economies, one can argue that agricultural reform involves a high uncertainty and thus a lower probability of success p. Depending on the reform blueprint, the use rights of land may be partly delegated to households for a short time period or they may be leased to households for a longer period of time. Alternatively, ownership of land may be transferred to households altogether. These different types of contracts have different incentive effects on households but also have different risk-bearing implications. Leasing contracts entail weaker incentives but do not impose big risks on households. While full ownership transfer gives higher incentives, it also imposes bigger risks. As the government is not fully aware of the exact tradeoff between incentives and risk-bearing ability of households (which in turn depend on other institutions in place), there is uncertainty about the effects of each type of contract. Blueprint uncertainty thus relates to the uncertainty about farmers' preferences and to the effects of existing risk-sharing arrangements. However, there is also uncertaintly about complementary reforms, such as reforms to improve the legal protection of private property rights. If these complementary reforms are not successful, this may negatively impact agricultural reform. Like industry, farming in the Soviet economy and in China were also organized as U-form and M-form. In the 1980s, farming tasks were divided among 11 ministries in the Soviet Union (Wegren, 1998). These tasks were coordinated by the central government through specialized ministries. Tractors were provided centrally by the so-called MTS stations. The tasks of providing inputs to the farmers, of managing their operations, storage, processing, transport, road infrastructure were all allocated to separate agencies over which collective farms had no control. Warehouses and processing plants were more likely to be located hundreds of kilometres away from farms (van Atta, 1993). Any change in grain production had to involve at least seven ministries: Ministries of Agriculture, Trade, Cereal and Grain Production, Tractors and Farm Machinery, Food Industry, Rural Construction, and Fertilizer. Any farm (private or collective) that changed crops from grain to vegetable production would have had to deal with these ministries plus other two ministries: Land Reclamation and Water Resources, and Fruit and Vegetable Farming. Regional governments did not have the authority to solve the coordination problems. Therefore farmers were dependent on different ministries and there were substantial problems particularly waste at the storage, transport and processing stages due to failures in coordination between production units, transport and storage (Wädekin, 1992). In contrast, In China, relatively self-contained regional governments (i.e., provinces, counties, and townships) were responsible for farming.

Consistent with the prediction of our model, under the U-form, the Soviet agricultural reform was implemented in the whole country. In 1989, the Central Committee of the Soviet Communist Party decided under Gorbachev's impulsion to launch a nationwide agricultural reform whereby farmers could lease land with long term contracts up to 50 years. In comparison, Chinese agricultural reform started with small scale experiments in the late 1970s in a couple of counties in Anhui Province and Sichuan Province, out of more than 2,000 counties in the country. The experimenting county governments were responsible for coordinating the reforms. Following the success of the pioneering experiments, the scale of the experiments was expanded and many other counties and other provinces implemented similar reform programs in later years. In 1980 about 14 percent of Chinese rural households became household farmers whereas the percentage was increased to 45 and 80 in 1981 and 1982 respectively. In 1984 when more than 98 percent of households became private farmers, the collective farming system was officially abandoned by the Chinese central government (Naughton, 1995).

We now give an example of full scale experimentation under the M form when p is relatively high. The example concerns the "dual-track approach" in price liberalization in China. Price liberalization is essential in any market oriented reform, and it involves uncertainty. In 1984, the Chinese government adopted a novel dual-track approach under which previously planned quantities and prices were maintained while at the same time markets were liberalized at the margin, so that the two prices co-existed. With this approach p is relatively high because only transactions at the margin are affected by the market price and inframarginal transactions are not. The resistance to reform was minimal as the planned sector was left unchanged and no one would thus lose from the reform (Lau, Qian and Roland, 2000). Despite the fact that China is known for its tendency to conduct small-scale experiments in reform, in this particular case, the Chinese government implemented the dual-track liberalization in all provinces and in all sectors within a very short time period. This is an example of full-scale experimentation consistent with our model.

8 Concluding Remarks

In this paper we analyzed issues of coordination in M-form and U-form organizations. M-form organizations are partitioned in self-contained units where complementary tasks are grouped together whereas in U-form organizations similar tasks are grouped together in specialized units. These different organizational forms have different implications for coordination of tasks inside the organizations. M-form organizations perform better in "attribute matching" between complementary tasks whereas U-form organizations have an advantage in specialization and can exploit the externalities between similar tasks which leads to better "attribute compatibility." These differences in organizational forms have interesting dynamic implications in terms of propensities to experiment with innovations. The M-form has the flexibility of using small scale experimentation, a possibility that is absent in the U-form due to the complications of coordination in attribute matching arising from its higher level of specialization. Small scale experimentation is particularly beneficial in the M-form when innovations are uncertain in the sense that they have a low probability of success. When innovations have a high probability of success, full scale experimentation is better and the U-form can dominate the M-form due to its advantage in specialization. We present evidence from the U.S. and from central planning in China and the Soviet Union that is consistent with the predictions of the model.

We would like to indicate one avenue for further research, that is, the change of the organizational form itself. In the paper, we have treated the organizational forms as given and compared their static and dynamic properties. But we have not formally analyzed the "life cycle" of organizations such as the gradual shift from the U-form to the M-form in business organizations documented by Chandler. Although the comparative statics from Section 5 may partly shed light on this issue by showing that an increase in the number of functions and complexity of products may give an advantage to the M-form despite the economies of scale of the U-form, more work is needed to understand the dynamics of organizational change.

Such organizational dynamics becomes even more complex in government organizations as compared to business organizations since political economy issues play a role on top of efficiency. Thus, for example, the reasons for why the Soviet Union did not manage to change from the U-form to the M-form organization are in part due to politics. In fact, such a change actually occurred under Khrushchev in the late 1950s and early 1960s but the latter was deposed and the U-form organization was reinstated afterwards. Therefore, understanding the reasons for change (or its absence) of organizational forms of government will have to incorporate political economy considerations.

9 Appendix 1. The One-Shot Experiment Model

In this Appendix we modify the original model in the following way: instead of assuming a continuous flow of experiment programs available over time, we allow for only one experiment program to be available. If this program is bad or not succesfully implemented, the organization will revert back to the old way. For simplicity, we assume away the compatibility problem (i.e., $s = 1$) and focus on the coordination problem only.

In this one-shot experiment model, the status quo (i.e., no experimentation) payoff under both the M-form and the U-form remains to be $V^S = \frac{R}{1-\delta}$,where δ is the discount factor.

In the M-form, under the full-scale experimentation strategy, the payoff at stage 0 becomes

$$\begin{aligned} V_o^{MF} &= -C + p\frac{2R}{1-\delta} + (1-p\frac{\delta R}{1-\delta}) \\ &= -C + \frac{R}{1-\delta}[2p + \delta(1-p)]. \end{aligned}$$

In the U-form, under the full-scale experimentation strategy, the payoff at stage 0 becomes

$$\begin{aligned} V_o^{UF} &= -\frac{C}{2} + p\left(\frac{2\lambda^2 R}{1-\delta} + \frac{2(1-\lambda^2)\delta R}{1-\delta}\right) + (1-p)\left(\frac{\delta R}{(1-\delta)}\right) \\ &= -\frac{C}{2} + \frac{R}{(1-\delta)}\left([2\lambda^2 + (1-\lambda^2)\delta]p + \delta(1-p)\right) \end{aligned}$$

In the M-form, the payoff at stage 0 under the small-scale experimentation strategy is given by

$$\begin{aligned} V_o^{MS} &= -\frac{C}{2} + p\left(\frac{3R}{2} - \frac{\delta C}{2} + \frac{2\delta R}{1-\delta}\right) + (1-p)\left(\frac{R}{2} + \frac{\delta R}{1-\delta}\right) \\ &= -\frac{C(1+p\delta)}{2} + \frac{R}{1-\delta}[p + \frac{1+\delta}{2}]. \end{aligned}$$

Note that the three payoff functions are somewhat different from the ones derived from the original model.

We define the critical value p^{MF} such that $V_o^{MF} = \frac{R}{1-\delta}$, the critical value p^{UF} such that $V_o^{UF} = \frac{R}{1-\delta}$, and the critical value p^{MS} such that $V_o^{MS} = V^S = \frac{R}{1-\delta}$. We derive that: $p^{MF} = \frac{(R+C)(1-\delta)}{R(2-\delta)}$, $p^{UF} = \frac{(R+\frac{C}{2})(1-\delta)}{\lambda^2 R(2-\delta)}$, and $p^{MS} = \frac{(R+C)(1-\delta)}{2R-\delta(1-\delta)C}$.The three critical values are exactly the same as in the original model. We now calculate the payoff difference between the M-form under the small-scale experimentation strategy and the M-form under the full-scale experimentation strategy:

$$V_o^{MS} - V_o^{MF} = \frac{1}{1-\delta}\left((1-p\delta)\frac{C}{2} - (p - \frac{1}{2})R\right).$$

Again, it is the same expression as in the original model. It is easy to derive that $\frac{\partial}{\partial p}V_o^{MF} > \frac{\partial}{\partial p}V_o^{MS} > 0$. We define p^* such that $V_o^{MF} = V_o^{MS}$, from which we derive $p^* = \frac{C+R}{\delta C+2R}$. Again, it has the same expression as in the original model.

We define $\widetilde{p}$ such that $V_o^{UF}(\lambda = 1) = V_o^{MS}$ and obtain $\widetilde{p} = \frac{R}{2R+\delta C}$. Again, it has the same expression as in the original model.

The reason that all the critical values have the identical expressions as in the original model is that the costs and benefits are comparable on a per period basis. We conclude that all the results from the original model with a continum of experimentation over time remain under the one-shot experimentation model.

10 Appendix 2. U-Form with Small-Scale Experimentation Across Units

Consider a strategy where the experiment applies to task 1A in unit 1 and task 2A in unit 2 in the U-form. The experimentation is thus carried out across the two units, but applied to the same product A. This is is a bit like the experiment in the M-form, in the sense that only product A is affected first by the experiment, not product B. We can write the recursive formula for the payoff at stage i in terms of the net present value V_i^{US}:

$$V_i^{US} = -\frac{C}{2}+p\{\lambda^2[\frac{(i+2)\,R}{2}+\frac{(i+1)\,R}{2}+\delta V_{i+1}^{US}]+\left(1-\lambda^2\right)(\frac{iR}{2}+\frac{(i+1)\,R}{2}+\delta V_i^{US})\}+(1-p)\left(\frac{iR}{2}+\frac{(i+1)\,R}{2}+\delta V_i^{US}\right).$$

Let $a = \frac{1}{1-(1-\lambda^2 p)\delta}$. We have

$$\begin{aligned} V_i^{US} &= a[-\frac{C}{2}+\lambda^2 p\left(i+\frac{3}{2}\right)R+[p\left(1-\lambda^2\right)+(1-p)](\frac{R}{2}+iR)+\lambda^2 p\delta V_{i+1}^{US}] \\ &= -a\frac{C}{2}+2(1+\lambda^2 p)a\frac{R}{2}+aRi+a\lambda^2 p\delta V_{i+1}^{US}. \end{aligned}$$

From the above recursive formula, we calculate

$$V_o^{US} = -a\frac{C}{2}\sum_{i=0}^{\infty}\left(a\lambda^2 p\delta\right)^i+(1+2\lambda^2 p)a\frac{R}{2}\sum_{i=0}^{\infty}\left(a\lambda^2 p\delta\right)^i+aR\sum_{i=0}^{\infty}i\left(a\lambda^2 p\delta\right)^i,$$

where $V_o^{US}$is finite because $a\lambda^2 p\delta = \frac{\lambda^2 p\delta}{1-(1-\lambda^2 p)\delta} < 1$ for all $\delta < 1$. We obtain the payoff at stage 0:

$$V_o^{US} = -\frac{C}{2(1-\delta)}+\frac{R}{1-\delta}\left(\frac{1}{2}+\frac{p\lambda^2}{(1-\delta)}\right).$$

To compare the relative advantage of the small-scale experimentation strategy under Formulation 1 with the full-scall experimentation strategy in the U-form, we calculate the difference in payoffs and obtain:

Proposition *Under the U-form, the payoff difference between the small-scale and the full-scale experimentation strategy is given by*

$$V_o^{US} - V_o^{UF} = \frac{R}{1-\delta}\left(\frac{1}{2} - p\lambda^2\right).$$

The relative advantage of the small-scale over the full-scale strategy is larger when p or λ is smaller.

The trade-off between the small-scale and the full-scale experimentation strategies under the U-form is similar to that under the M-form, with an important difference on the option value part. Comparing the above expression with $V_o^{MS} - V_o^{MF} = \frac{1}{1-\delta}\left((1-p\delta)\frac{C}{2} + (\frac{1}{2} - p)R\right)$,we found that under the U-form, the small-scale experimentation strategy does not have the option value of waiting as compared with the full-scale experimentation strategy. The relative advantage is then completely determined by the term $\frac{1}{2} - p\lambda^2$. When $p\lambda^2 > \frac{1}{2}$, it is the cost of delaying experiment in the entire organization. When $p\lambda^2 < \frac{1}{2}$, it is the cost saving from the delay, because the success chance of the experiment is too small.

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