Horizontal vs. Vertical Information Structure of the Firm

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This paper compares the efficiency of two information structures, hierarchical and vertical, of the firm in coordinating operational decisions among technologically interrelated shops whose costs are uncertain. In the first, the capability of management to monitor and respond to emergent events at the shop level is bounded. In the second, production decisions are coordinated among shops without the centralization of information, whose capability of semiautonomous problem solving improves through learning by doing. This study is motivated by a U.S.–Japan comparison of industrial organization.

The objective of this paper is to compare the efficiency of two informational structures of the firm in coordinating operational decisions among interrelated units (shops) whose cost conditions are uncertain. One informational structure is hierarchical—management possesses a perfect a priori knowledge of the technological possibilities of shops, but is incapable of perfect monitoring of emerging events affecting these technologies, and/or having rapid corrective actions implemented at shops. The second structure is horizontal—production decisions are coordinated among semiautonomous shops that have only incomplete knowledge of technology at the outset, but gradually become capable of responding to emerging events more quickly by better uses of on-the-spot knowledge. This paper is exclusively concerned with efficiency properties of the two informational structures; and the issue of their incentive compatibilities is relegated to other work.[1] The comparison of the two structures is purely analytical, but I hope to provide a conceptual framework for a U.S.–Japan comparison of industrial organization (such as workshop organization, internal firm organization, manufacturer-suppliers relations, etc.). Another obvious application would be to production coordination in the socialist economy. In this application, the management should be read as the ministry of industry and shops as firms.

I. Motivation of the Study

This section, as a way of motivating the present study, describes several stylized contrasts between Japanese and U.S. firms pertinent to the operation of the internal organization, as well as to the degree and mode of integration. These references are mainly directed toward large unionized firms in the manufacturing industry.

A. *Specialization vs. Learning*

There is a distinct difference in the way work is organized on the shop floor in the typical Japanese firm (denoted J firm) and the typical American (unionized) firm (denoted A firm). In the A firm, workers' jobs are specified according to a job classification scheme stipulated in a collective agreement,

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[1]See my 1985 paper for an exploratory attempt on this issue.

and each worker is required to perform his (her) own specialized task according to formal or informal rules, operation manuals, supervisor's directives, etc. When irregular events happen, such as the absenteeism of workers, breakdown of machinery, or production of an abnormally high rate of defective products, remedies are usually sought by supervisors, reliefmen, repairmen, engineers, and the like. Manual workers are not specifically responsible for coping with unexpected emergent events.

In contrast, in the *J* firm, workers' jobs are not specified in detail and workers rotate among various jobs with some frequency within, as well as beyond, workshops. Through this practice, workers are gradually made familiar with the whole work process and become capable of coping with unexpected emergencies. As Kazuo Koike convincingly argues, such capability constitutes one of the most important components of the workers' skills.[2] In fact, there is a considerable degree of delegation of decision-making power to the group of workers on the shop floor. They are encouraged to solve emergent problems by themselves and improvise improvements on designed work processes. When needed, the repairmen, inspectors, and engineers are willing to cooperate with the workers in joint problem solving.

The emphasis at the *A* firm is on the efficiency attained through job specialization and rational hierarchical control, whereas at the *J* firm, it is on the workers' grass roots capability to cope with emergent events fostered by collective learning by doing. The Japanese approach has proved to be effective from a quality- and cost-control point of view in industries such as steel and automotive manufacturing where cost reduction has been attained largely through improvements on fairly established technology. But, will it be equally effective in the high-tech industry where the speed of technological obsolescence is likely to be high, and general educational training seems to be gaining importance as a component of workers' skills?

B. *Hierarchical Control vs. Horizontal Coordination*

In the uncertain world where complete contingent contracts cannot be written because of "bounded rationality" of concerned agents, emergent events have often to be dealt with, *ex post*. Different modes of transactions would emerge, depending upon how and by whom they are dealt with. In the *A* firm, decisions involving discretion are normally hierarchically organized according to their importance. In fact, some authors argue that the layering of specialized decision making in order to cope with emergent events for which detailed specification of appropriate actions cannot be formulated *ex ante* is the essence of hierarchy.[3]

In the *J* firm as well, decisions involving a high degree of uncertainty, such as investment and research and development, as well as those responding to a high degree of irregularity are placed under hierarchical control. However, once an overall framework for production is laid down by such strategic decisions, horizontal informational exchanges and semiautonomous coordination of operations by relevant subordinates are emphasized. In contrast to the prominent role played by the expediter in the *A* firm, the coordination of production between *J* firm workshops to facilitate a smooth production flow along the production stream is often done by horizontal communication without the intervention of a supervisor, as the highly publicized "kanban-system" at the Toyota factory exemplifies. A kanban is a tag-like card put in a vinyl envelope which orders from the immediately upstream shop (or the supplier) a particular amount of materials, tools, parts, or processed goods at a particular time. Robert Cole aptly draws an analogy between this practice and "the

[2]The practice of job rotation in the Japanese workshop is described and its implication to skill formation is thoroughly discussed in Koike (1984). Based upon his own extensive field work, Koike (1985) also maintains that an important part of the workers' skills consists of their ability to cope with unexpected emergencies.

[3]See for example, David Kreps (1984).

system we use in restocking supermarkets" (1985, p. 106). Although apparently crude, the kanban system is considered to have contributed greatly to reducing inventory and waste, uncovering bottlenecks, allowing for rapid adjustment of product lines, and reducing managerial personnel.[4]

The emphasis at the *A* firm is on the efficiency attained by rational technocratic control, whereas, in the *J* firm, it is the efficiency attained through the use of on-the-spot knowledge and rapid problem solving through learning by doing. In the former, decisions may be made consistently and rationally from the organizational point of view, once an emergent problem is recognized. However, if the quality of information is poor, the manager may be slow and imprecise in recognizing the problems to be handled. Also, subordinates, by not being included in decision making, may lack the motivation to report problems and to implement the hierarchical order in a precise and swift way. Thus using the hierarchical system involves the cost of monitoring due to the bounded rationality of the supervisors, and the cost of implementation due to the lack of incentives of the subordinates.

On the other hand, in the *J* firm, subordinates may be motivated to respond to emergent events swiftly in a way which they conceive to be consistent with the organizational purpose, provided that organizational goal is internalized by them. However, the ability of subunits to coordinate their decisions between themselves in a way actually consistent with the organizational purpose would be limited by their partial understanding of the whole mechanism operating within the firm. This understanding can be enhanced by learning by doing, but is costly in terms of time. Also, the problem-solving capability of subunits through horizontal coordination would be limited by the lack of centralization of information concerning emergent events which affect various other subunits.

[4]For more details on the kaban system, see Cole (1985) and Yashuhiro Monden (1983).

Which of the two information and decision-making structures, hierarchical or horizontal, is more effective for controlling the total costs of the system in changing environments? How does the complexity of technological interdependencies of subunits affect their relative efficiency performances?

C. *Integration vs. Quasi Disintegration*

The degree of integration of the *A* firm is normally much higher than that of the *J* firm. A joint U.S.–Japan study of the automotive industry estimates that 45 percent of a car's purchased value is provided by U.S. manufacturers and their wholly owned subsidiaries, with 55 percent being provided by outside suppliers. Only 25 percent of a car's purchase value is made in-house for Japanese manufacturers.[5] This difference is due to an extensive reliance of Japanese major manufacturers on suppliers which are normally smaller in size and often referred to as "subcontractors."[6]

A reason often cited for the extensive deployment of the subcontracting relations by the *J* firm is that, since the rate of its growth was so fast, it could not generate enough internal resources for integration to an extent comparable to that which the *A* firm had achieved over its longer course of growth. This may partially explain the genesis of the extensive subcontracting relations observed in the Japanese manufacturing industry. But if this was the only reason, and there was no intrinsic comparative advantage of a subcontracting relationship over more complete integration, the former would have been gradually replaced by the latter as the growth rate of the economy slowed down and the

[5]See Cole and Taizo Yakushiji (1984, p. 153–54).

[6]Precisely speaking, the subcontractor is a legal concept in Japan. According to Basic Law for Medium and Small Enterprises and Law for Preventing the Delay of Payment of Subcontracting Fees, firms with 300 or fewer employees, or with 100 million yen or less paid-in capital, are classified as subcontactors when they have contractual relations with larger firms for supplying parts, processed products, matrials, etc. Excellent studies on subcontracting relations in the Japanese automotive industry are found in Banri Asanuma (1985) and Cole and Yakushiji (ch. 9). Also see my book (1984a).

accumulation of internal resources of the J firm progressed in the 1970's and the early 1980's. On the contrary, the degree of reliance of the J firm on subcontracting relationships has increased over this period.[7] Furthermore, the relationship between the parent firm and its subcontractors has come to be much more systematic and formalized. The large J firm maintains long-term, direct relations with primary subcontractors that are loosely organized into associations of cooperating firms (kyoryoku-kai); and those primary subcontractors in turn maintain relations with secondary subcontractors, etc. Instead of a highly integrated, hierarchical firm, we observe a quasi-disintegrated, quasi-hierarchical group of firms (hereafter referred to as the J-firm group) in which subcontractors maintain semiautonomous control of production, although the main manufacturers typically have minority equity holdings in their first-tier suppliers, and exercise substantial influence over the direction of research and development as well as over investment decisions by the latter.

The benefits of integration vis-à-vis the market have been discussed by many authors. Integration may be able to reduce the cost of market transactions caused by the opportunistic and inefficient behavior of a seller and buyer in situations where either the buyer or the seller must make transaction-specific investments (Oliver Williamson, 1975, and Benjamin Klein et al., 1978), and/or where it is too costly for one party to specify a long list of the particular rights it desires over another party's assets (Sanford Grossman and Oliver Hart, forthcoming). Another motive for integration may be to communicate uncertain information regarding upstream supply conditions more efficiently (Kenneth Arrow, 1976).

But as Grossman and Hart argue, the transaction-cost and information-cost-based arguments did not elucidate where the benefits of integration will stop. Ronald Coase (1937) states that the size of the firm is limited by the capacity of the single owner in the number of activities he can manage. This is unconvincing, however, because organizational innovation such as the multidivisional form may overcome this limit (Williamson, 1975). Facing this problem, Williamson (1985) came to argue that excessive integration may sacrifice the efficiency possible under the "high-powered" market incentive. Consequently, he states, if benefits of high-powered incentives are potentially high, while the transaction in question involves a substantial degree of asset specificity, "new hybrid forms" of organization other than the firm may appear in response. I submit that the information costs may also increase from excessive integration and that may provide another reason for the emergence of the J-firm group, which is an example of such a hybrid form.

The J-firm group may combine some of the benefits of both integration and the market. Since the relationship between the parent firm and subcontractors is of a long-term nature, both would come to have a fairly good knowledge of each other's technology, and inefficient price haggling would not be a serious problem. In Williamson's terminology, conditions of "information impactedness" (1975, pp. 31–33) are more easily overcome and, even when they appear, are less likely to give rise to strategic behavior. Also, since an implicit/explicit arrangement of profit sharing is the normal practice in this long-term relationship,[8] underinvestment in transaction-specific assets may be avoided to both parties' mutual advantage. On the other hand, since the long-term relationship is maintainable only if it is beneficial to both parties, but is otherwise dissolvable albeit at some cost, the "midpower" market incentive would operate within the J-firm group; that is, subcontractors would take greater care in cost control and quality control of their production as compared to in-house supply divisions. But these relative advantages still remain hypothetical, unless an efficient information system between the parent firm and its subcontrators for coordinating their operations is possible without consistent hierarchical direction under an in-

[7]See my paper (1984b).

[8]See my paper (1985) and also Asanuma.

tegrated firm or the efficient signal of competitive prices.

As indicated above, one of the premises for the efficiency of the *J*-firm group is technological knowledge sharing between the parent firm and its subcontractors for mitigating the problem of opportunistic behavior. However, within a general framework of knowledge sharing, day-to-day monitoring of emergent events affecting the cost efficiency of productive operations and/or product quality may be delegated to subcontractors. Then the information exchange necessary for rapid corrective action can be made more direct by coordination between the relevant operational units (for example, between parts-supplying subcontractors and the assembly shop of the parent firm, between first-tier and second-tier subcontractors, etc.), without the intermediary of an elaborate, centralized control mechanism

However, is this quasi-decentralized coordination within the *J*-firm group not a crude information system? Is it not likely to be the case that the administrative costs of a highly integrated firm will be reduced in the near future by the rapidly growing information-processing technology and more reliable robotic technology? Or will the quasi-disintegrated group continue to exhibit higher transaction-cost savings in spite of these new developments?

I have described three stylized contrasts between the *A* firm and the *J* firm/*J*-firm group. They include oversimplifications inevitable in any stylized formalization. Neither a pure *J* firm nor a pure *A* firm exists. Any American or Japanese firm can contain some aspects of both. There is also much anecdotal evidence that many American firms have recently been adopting some elements of the *J* firm, such as the simplification of the job classifications scheme, an increased delegation of decision-making authority to line organizations, more systematic relationships with suppliers, etc. One may also argue that the three issues discussed above are only mildly related to each other. I submit, however, that if these three stylized contrasting features are taken together as a benchmark from the informational structure point of view, one fundamentally common issue arises. That is the issue of relative efficiency of what I call "horizontal coordination" based on learning by doing vs. rational "hierarchical control" based on specialism.

Suppose that strategic decisions (such as those that involve investment as well as the direction of research and development) are made by superordinates (the management of the firm). Given these decisions, actual operations of subunits (shops) must be adjusted and coordinated accordingly as emergent events affect the efficiency of each unit. In order for efficient coordination to occur, the monitoring and identification of emergent events affecting cost efficiency as well as quick implementation of corresponding operational decisions are imperative. In the horizontal coordinating system, these tasks are delegated to subunits performing relevant operations that are limited in their capacity to recognize a relevant emergency at the outset. Even if they do, since the centralized use of information concerning emergent events is absent, problem solving at the subunit level may not satisfy the first-best condition. But, through learning by doing, the subunits can improve their ability to perceive emergent problems and to find corresponding solutions. Once a problem is recognized and a corresponding solution found, the subunits should be able to implement it quickly.

On the other hand, in the hierarchical control system, management has a priori knowledge of the overall production technology. But their capacity to identify emergent events affecting production technology of subunits and to enforce the implementation of appropriate operational decisions upon said subunits may be limited and costly, simply because management is removed from operational activities. In other words, the rationality of the superordinates is apt to be "bounded."

Thus the relative efficiency of the two systems depends upon the following factors: the ability of subunits to learn how technology is affected by emergent events and how these events should be dealt with (the speed of learning); the initially endowed ability of subunits to understand the nature of technology as well as the speed of obsolesence of technology; and the ability of management to identify emergent problems at the subunit level as well as to enforce the implementation of operational decisions upon subunits as quickly as possible (the quality of hierarchical informational structure and the reward system). In the next section, I construct a simple analytical model of horizontal coordination in which learning by doing by subunits would play a significant role, and a model of hierarchical control whose rationality is bounded; I then analyze how the factors affect the relative efficiency of the two models. As I have indicated, it is likely that the aspects of hierarchical control and those of horizontal coordination may coexist in any single firm. Therefore, the following model comparison may be understood as an analytical device for considering the problem of an optimal mix of the two approaches within a firm.

II. The Model

Let us employ the production model due to Jacque Cramer (1980) and John Geanakopolos and Paul Milgrom (1985) as a basis for the comparative analysis of the two informational structures of the firm. Let us consider a system composed of n technologically interrelated subunits called shops, identified by index $i=1,\dots,n$. Let $x_i \in R^s$ denote a vector of net production assignment of the ith shop, with the convention that negative components indicate inputs and positive components outputs. Suppose that the cost incurred by shop i to realize a production assignment x_i is represented by a quadratic cost function:[9]

$$C_i(x_i, u_i) = [x_i - u_i]'B_i[x_i - u_i] + A_i \qquad (i=1,\dots,n)$$

where B_i is a positive semidefinite matrix with at least one diagonal element being strictly positive, A_i is a constant matrix, and $u_i \in R^s$ is a random variable representing cost uncertainty with $E[u_i]=u_i^*$, $E[(u_i - u_i^*)(u_i - u_i^*)'] = \operatorname{var} u_i$, and $E[(u_i - u_i^*)(u_j - u_j^*)'] = 0$ for $i \neq j$. The cost C_i may represent the "outlay" from the system or the effort expenditure level incurred by shop i to realize its production assignment.

The objective of the system is to realize a net output target:

$$x^* = \Sigma x_i$$

with the expected minimum aggregate cost

$$E[C(x,u)] = \Sigma E[C_i(x_i, u_i)]$$

responding to emergent events *ex post*. Given an observed event $u=(u_1,\dots,u_n)$, the solution to this problem is

$$x_i^p = u_i + B_i^{-1}B[x^* - U] \qquad (i=1,\dots,n) \tag{1}$$

where $B = [\Sigma B_i^{-1}]^{-1}$; $U = \Sigma u_i$.

If the system can identify emergent events and implement corresponding cost-minimizing solutions immediately, the expected total cost under this perfect control is

$$C^p = E\{\Sigma[x^* - U]'BB_i^{-1}B[x^* - U]\} + \Sigma A_i$$
$$= C^* + \operatorname{tr}[B \operatorname{var} U]$$

where $C^* = [x^* - U^*]'B[x^* - U^*] + \Sigma A_i$

$U^* = \Sigma u_i^*$

$$\operatorname{tr}[B \operatorname{var} U] = E\{[U - U^*]'B[U - U^*]\}.$$

On the other hand, if the system cannot identify emergent events, the system routinizes its production at the level

$$x_i^n = u_i^* + B_i^{-1}B[x^* - U^*] \qquad (i=1,\dots,n)$$

so as to realize the minimum expected total

[9] Arrow (1985) cautions against the use of a quadratic function for the study of information structure. As he states, the use of the quadratic function sometimes leads to strange analytical results. I assume that the quadratic representation of technology is a local approximation for nonlinear technology.

cost under no *ex post* information condition:

$$C^n = \Sigma E\{[x_i^n - u_i]' B_i [x_i^n - u_i]\} + \Sigma A_i$$
$$= C^* + \Sigma \operatorname{tr}[B_i \operatorname{var} u_i],$$

where

$$\operatorname{tr}[B_i \operatorname{var} u_i] = E\{[u_i - u_i^*]' B_i [u_i - u_i^*]\}.$$

The solution x_i^n corresponds to Martin Weitzman's (1974) quantity solution in his treatise on price vs. quantity. We are interested in two control mechanisms whose cost performances lie somewhere between the perfect control case and the no *ex post* information case.

A. *Bounded Rational Control*

Let us consider a control mechanism in which the managing unit sends assignments to each shop. Management has perfect a priori knowledge concerning technologies of shops (i.e., it knows B_i's) and is capable of calculating the optimal solution once an emergent event is identified, but its rationality is bounded in two respects: it can identify emergent events only imprecisely, and can have production assignments implemented only with some delay—meanwhile, events may change.

First, suppose that the perception u_i^{br} of management of an emergent event u_i is errored in such a way that

$$u_i^{br} = u_i + v_i \qquad (i = 1, \ldots, n)$$

where v_i is a stochastic vector with $E[v_i] = 0$ and $E[v_i v_i'] = \gamma E[(u_i - u_i^*)(u_i - u_i^*)']$ for some constant γ. Given the quadratic loss function, expected loss is minimized by setting $u_i = u_i^{br}$ in equation (1). Production assignments would therefore be

$$x_i^{br} = u_i^{br} + B_i^{-1} B[x^* - \Sigma u_i^{br}] \qquad (i = 1, \ldots, n).$$

Second, it is assumed that time Δ elapses between the perception of an emergent event by the management and the implementation of the corresponding production assignments and that emergent events constitute a first-order autoregressive process defined by

$$du_i(t) + hu_i(t)\,dt = d\mu_i(t) \qquad (i = 1, \ldots, n),$$

where h is a positive parameter representing the rate at which the environment forgets the past history of u_i and $\{\mu_i\}$ is a random process with orthogonal increments. It can be shown that the process $u_i(t)$ defined by the above equation satisfies the following relation:[10]

$$E\{[u_i(t) - u_i^*][u_i(t + \Delta) - u_i^*]'\} = e^{-h\Delta} \operatorname{var} u_i(t).$$

When an event $u_i^{br}(t)$ $(i = 1, \ldots, n)$ is perceived by management and the corresponding production assignments are implemented after time Δ, the expected instantaneous total cost at the time of implementation would be

$$C^{br} = \Sigma[x_i^{br}(t) - u_i(t + \Delta)]' B_i \times [x_i^{br}(t) - u_i(t + \Delta)] + \Sigma A_i$$
$$= C^* + \operatorname{tr}[B \operatorname{var} U] + (\gamma + 2(1 - e^{-h\Delta})) \times \{\Sigma \operatorname{tr}[B_i \operatorname{var} u_i] - \operatorname{tr}[B \operatorname{var} U]\}$$
$$= C^n + (\gamma + 1 - 2e^{-h\Delta})(C^n - C^p).$$

Actually the production assignment x_i^{br} $(i = 1, \ldots, n)$ does not minimize the expected cost given the perception error and the time lag in response to emergent events. This can be easily seen from the observation that if γ or $h\Delta$ is sufficiently large, C^{br} can exceed the cost C^n under no *ex post* information. In such cases it is better not to react to changing events, but to make routine the noninformation solution (i.e., the Weitzman solution).

[10]See A. M. Yaglom (1962, chs. 2 and 3).

If management is rational enough to recognize its bounded rationality, what it ought to do to reduce the expected cost is to mix the production assignments x_i^n and x_i^{br}.[11] In other words, before utilizing perceived information u_i^{br}, management ought to shrink it to the expected value. Let

$$x_i^r(t+\Delta) = \alpha x_i^{br}(t) + (1-\alpha)x_i^n \quad (i=1,\ldots,n).$$

Then the aggregate instantaneous cost would be

$$C^r = C^n + \{(1+\gamma)\alpha^2 - 2\alpha e^{-h\Delta}\}(C^n - C^p).$$

By choosing $\alpha = e^{-h\Delta}/(1+\gamma)$, the expected cost would be minimized at the level

$$C^r = C^n - e^{-2h\Delta}(C^n - C^p)/(1+\gamma).$$

Suppose that the time discount rate of the system is δ. (It is assumed that the rate of discount captures the effect of technological obsolescence as well.) Then the sum of discounted expected costs from the present to the infinite horizon would be

$$\int_0^\infty e^{-\delta t} C^r dt$$

$$= (1/\delta)\{C^n - e^{-2h\Delta}(C^n - C^p)/(1+\gamma)\}.$$

B. *Learning by Doing*

An alternative mechanism in controlling the system is the horizontal coordination in which decisions on inputs and outputs of shops are coordinated among relevant shops. But the shops capacity to coordinate is limited in two respects: the ability to identify emergent events is initially limited and can only be improved upon over time through learning by doing; and the horizontal coordination by shops is imperfect as each shop lacks information concerning technologies of other shops except for those directly related.

[11]Since I am concerned with a quadratic programming, the optimal solution is a linear function of x_i's.

However, once shops acquire the skill to identify emergent events affecting their own and their transaction partners' cost conditions, they can implement (at least locally) an appropriate production plan without delay. First, let us concentrate upon the effect of learning by doing by assuming that shops can somehow find and implement the optimal solution of production corresponding to a perceived emergent event. Let us call this mechanism—in which the perceptive abilities of shops improve over time and they become perfectly capable of calculating optimal solutions—quasi-horizontal coordination. The problems arising from imperfect coordination due to the lack of centralized technological information will be considered later.

Assume that the shops' perceptive abilities are represented by the probability f of identifying true emergent events. Suppose that, if the shops identify a situation, an optimal solution correspondent to it is implemented. If not, the no *ex post* information solution x_i^n $(i=1,\ldots,n)$ is routinized. Then the instantaneous expected total cost of the systme under this quasi-horizontal coordination would be

$$C^{qh} = C^n - f(C^n - C^p).$$

Suppose that the probability of problem recognition improves over time through learning by doing according to

$$df(t)/dt = kf(t)\{\log[1/f(t)]\},$$

where k is a positive parameter representing the rate of learning. Upon integration, we obtain the Gomertz growth model

$$f(t) = \exp\{-\beta e^{-kt}\}.$$

When $t=0$, $f(0)=e^{-\beta}$ so that the inverse of β may be identified with the initial ability of shops as regards to problem identification. As t goes infinity, f approaches one.

The sum of expected discounted costs under the quasi-horizontal coordination from the present to the infinite horizon is

$$\int_0^\infty e^{-\delta t} C^{qh}(t)\,dt = (1/\delta)C^n - \int_0^\infty \exp(-\delta t - \beta e^{-kt})\,dt(C^n - C^p)$$
$$= (1/\delta)C^n - (1/k)\int_0^\infty \exp\{-(\delta/k)y - \beta e^{-y}\}\,dy(C^n - C^p).$$

By setting $\delta/k = \theta$

$$= (1/\delta)\{C^n - \theta\beta^{-\theta}\nu(\theta,\beta)(C^n - C^p)\},$$

where ν is the incomplete *gamma* function:[12]

$$\nu(\theta,\beta) = \int_0^\beta e^{-s}s^{\theta-1}\,ds.$$

The value of $\theta\beta^{-\theta}\nu(\theta,\beta)$ is monotonically decreasing in both θ and β. By comparing the sum of expected discounted costs under the bounded rational control and the quasi-horizontal control, we have the following proposition.

PROPOSITION 1: *The sum of discounted expected costs under quasi-horizontal coordination is smaller than that under bounded rational control if and only if*

$$e^{-2h\Delta}/(1+\gamma) < \theta\beta^{-\theta}\nu(\theta,\beta).$$

Thus the relative advantage of quasi-horizontal coordination is positively related to the lag in hierarchical adaptation to emergent new events represented by Δ, to the degree of imprecision of management's perception represented by γ, to the relative ratio of the rate of learning of shops to the time discount rate represented by θ, and to the initial ability of shops to perceive emergent events represented by the inverse of β. This is independent of technological data represented by B_i's and var u_i's. Specifically,

[12]See I. S. Gradshteyn and I. M. Ryzhik (1980, pp. 308, 940).

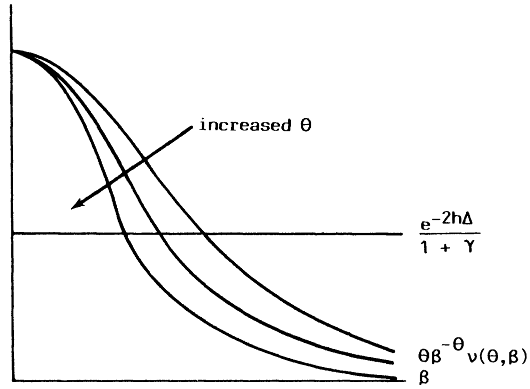

FIGURE 1

if $\theta = 1$, then $\nu(1,\beta) = 1 - e^{-\beta}$ so that the condition can be simply written as

$$e^{-2h\Delta}/(1+\gamma) < \beta^{-1}[1 - f(0)].$$

Since $\lim_{\beta\to 0}\theta\beta^{-\theta}\nu(\theta,\beta) = 1$ and $\lim_{\beta\to\infty}\theta\beta^{-\theta}\nu(\theta,\beta) = 0$, it holds that

COROLLARY 1: *The value of β must be smaller than a certain strictly positive maximum value in order for the quasi-horizontal coordination to be relatively advantageous. This maximum value of β decreases as h, γ, and Δ decrease and as θ increases.* (*See Figure* 1.)

This corollary suggests that in order for the quasi-horizontal coordination to be relatively advantageous, the initial ability of shops to identify emergent events must be higher than a certain level. Even if the rate of learning is very high relative to the time discount rate, learning alone cannot make the quasi-horizontal coordination a superior mechanism.

C. *Imperfect Horizontal Coordination*

Let us now take into account the imperfect ability of shops to coordinate their production decisions. Suppose that transactional decisions concerning any products are coordinated between the relevant supplier shop(s) and the relevant user shop(s). Suppose that, with probability f evolving as already specified, they are able to mutually identify emergent events affecting each others' cost condition associated with the transaction of that particular product, as well as to share technological knowledge concerning mutual B_i's. When they do so, they agree upon the particular amount of the transaction of that product which minimizes the joint costs, assuming other inputs and outputs are fixed at the solution under no *ex post* information. If they cannot share information, they routinize the transaction at the level of the no *ex post* information solution. For example, suppose that product k is transacted between shop i and shop j. Further, suppose that it is only these two shops that either produce or use the product k. Then shop i and shop j, mutually recognizing the true value of u_{ik} and u_{jk} with probability f, choose x_{ik} and x_{jk} which would minimize the joint costs subject to the constraint $x_{ik} + x_{jk} = x_k^*$, assuming that other components of x_i and x_j are fixed at the level specified by x_i^n and x_j^n and those of u_i and u_j are fixed at the level specified by u_i^* and u_j^*.

In general, the local joint cost minimizing, when *ex post* information is shared by relevant shops, requires that

$$B_i(x_i^n - u_i^*) + \hat{B}_i[(x_i - u_i) - (x_i^n - u_i^*)] = \lambda \quad (i=1,\dots,n)$$

and $\Sigma x_i = x^*$ for some intrafirm shadow price λ, where

$$\hat{B}_i = \begin{bmatrix} b_{i,11} & & & & 0 \\ & \ddots & & & \\ & & b_{i,jj} & & \\ & & & \ddots & \\ 0 & & & & b_{i,ss} \end{bmatrix}.$$

From this, the imperfectly coordinated solution x_i^{ip} satisfies

$$x_i^{ip} = u_i + B_i^{-1}B[x^* - U^*] - \hat{B}_i^{-1}\hat{B}[U - U^*]$$
$$= x^p + [B_i^{-1}B - \hat{B}_i^{-1}\hat{B}][U - U^*] \quad (i=1,\dots,n),$$

where $\hat{B}_i^{-1}$ is a diagonal matrix with the jth element being $1/b_{i,jj}$ if $b_{i,jj}$ is positive and zero otherwise. Then the total instantaneous expected cost under the imperfect horizontal coordination when the true event is perceived is

$$C^{ip} = C^p + \mathrm{tr}\big[\big(\Sigma \hat{B}\hat{B}_i^{-1}B_i\hat{B}_i^{-1}\hat{B} - B\big)\mathrm{var}\, U\big]$$
$$= C^n - \Sigma\big\{\mathrm{tr}\big[\big(B_i - \hat{B}\hat{B}_i^{-1}B_i\hat{B}_i^{-1}\hat{B}\big)\mathrm{var}\, u_i\big]\big\}.$$

One can define efficiency ratio of the imperfect horizontal coordination relative to perfect control by

$$\eta(B) = (C^n - C^{ip})/(C^n - C^p)$$
$$= \frac{\Sigma\big\{\mathrm{tr}\big[\big(B_i - \hat{B}\hat{B}_i^{-1}B_i\hat{B}_i^{-1}\hat{B}\big)\mathrm{var}\, u_i\big]\big\}}{\Sigma\{\mathrm{tr}[(B_i - B)\mathrm{var}\, u_i]\}}$$

Following the same reasoning as in the case of the quasi-horizontal coordination, we can derive

PROPOSITION 2: *The imperfect horizontal coordination based upon learning is superior to the bounded rational control if and only if*

$$e^{-2h\Delta}/(1+\gamma) < \theta\beta^{-\theta}\nu(\theta,\beta)\eta(B).$$

As all off-diagonal elements of B_i $(i=1,\dots,n)$ approach zero, $\eta(B)$ approaches one. Therefore, somewhat loosely we can claim

COROLLARY 2: *Given other parameters, the relative advantage of the imperfect horizontal coordination would increase vis-à-vis the bounded rational control, as the technological matricies, B_i, become more strongly dominant-diagonal.*

Roughly speaking, the more strongly dominated the marginal cost of each output is by the output level of that product than anything else, the more the relative advantage of the imperfect horizontal coordination would increase vis-à-vis the bounded rational control. This means that if the technology is characterized by near-constant returns to scale, the imperfect horizontal coordination would not perform well. On the other hand, it would perform relatively well when there is a separate capacity constraint for each output.

III. Concluding Remarks

Section II above formalizes the intuitive notion that decision-making power in the Japanese industrial organization is, as far as operational decisions are concerned, relatively widespread. This "decentralized" tendency is to use the on-the-spot knowledge of subunits (workers, in-house shops, and relatively smaller subcontractors). Also, in order that the localized use of on-the-spot knowledge would not lead to inefficient strategic haggling between subunits, sharing of knowledge among neighboring subunits (among workers, among shops, and between prime contractors and subcontractors) is emphasized. The accumulation of on-the-spot knowledge as well as sharing of knowledge can be, needless to say, fostered only over time. That is one of the primary reasons why the Japanese tend to emphasize long-term relations such as "lifetime" employment and stable relational contracts with subcontractors.

On the other hand, emphasis on specialization in the United States seems to have two consequences: First, as jobs become more specialized and standardized, a separate market for each job tends to develop outside the firm, facilitating interfirm mobility of workers. Second, in order to integrate specialized and compartmentalized jobs within the firm, the integration itself has become a specialized function of management. Thus American industrial organization is characterized relatively more by interfirm mobility of workers cum vertical control, whereas Japanese industrial organization is characterized relatively more by intrafirm mobility (rotation) cum horizontal coordination. Needless to say, this difference is only a matter of relative degree and should not be taken as an absolute principle.[13] I simply suggest that there may be a close connection between labor market characteristics and information systematic characteristics of the firm from a comparative perspective.

How does the relative difference between the *A* firm and the *J* firm in their approach toward coordination of operational decisions interact with the mode and direction of more strategic decision making such as research and development? This is an interesting question, however, it is beyond the scope of this paper. I believe that the distinction of the two types of knowledge emphasized in their respective approaches may have some bearing upon this question.

As Hayek (1945) emphasized in the context of the price mechanism vs. central planning, economically useful knowledge may not be limited to that which can be described in terms of formal language (for example, blueprints, books, patents), but may also include intangible skills, undefined tacit knowledge, etc., as generated and transmitted through experiences and on-the-spot contacts. The Japanese firm that relies more on collective learning by doing and informal knowledge sharing in its operations seems to place relative emphasis in research and development efforts on systematizing and developing potentially useful knowledge of the second kind, collectively accumulated within the firm through production experiences. Even when new knowledge is acquired from outside the firm in the form of patents and the like, that new knowledge is often reinterpreted and developed in reference to the firms' own productive experiences. For example, some of the firms most active in the development of biotechnology in Japan are traditional food-processing firms that strive for possible adaptation of their amino acid fermentation and/or brewing techniques to screening and breeding of new micro organisms that have been genetically modified by the use of recombinant DNA. On the other hand, the American firm based on professional specialization and managerial vertical control in its operations seems to place relative emphasis on the scientific efforts of professionally trained researchers in *R&D* under the entreprenurial direction of top management.

[13]This contrast of interfirm mobility vs. intrafirm mobility between American industry and Japanese industry is well described in Cole (1979). See also Masanori Hashimoto and John Raisian (1985).

Of course, when the Japanese firm systematizes and develops its own production experiences, the infusion of researchers' and engineers' expertise is indispensable. But even for researchers and engineers, on-the-job training is regarded as equally important as formal training. Therefore, quitting by researchers and engineers in midcareer is discouraged by a system of seniority salaries and retirement benefits contingent on lifetime employment. As a consequence, the rate of interfirm mobility is relatively low even for researchers and engineers. Some argue that the low rate of interfirm mobility of researchers deters rapid technological diffusion without possible government assistance,[14] but one may counterargue that the lower exit rate of researchers reduces the risk of premature leakage of research results out of the firm, thus inducing the firm to finance *R&D* more actively without fearing the free riding of quitters.

Professional specialization in *R&D* in the United States makes professional communications across the boundary of firms, as well as interfirm mobility of researchers, relatively more frequent. Also, one of the possible implications of the vertical control approach is the ease of adding new subunits to a system, or starting an entirely new system, by managerial initiatives. The relatively high mobility of researchers combined with the relative ease of structural reorganization makes it easier to commercialize new knowledge in the form of acquisition of small innovative firms by large established firms or spinoffs of venture businesses. In contrast, the internal diversification or spinoffs of semiautonomous subsidiaries by established firms is the more dominant form of commercializing new knowledge in Japan.

Again I emphasize that the difference in these two approaches to the generation, development, and commercialization of new knowledge is simply a matter of relative degree, but I submit that it is not reasonable to neglect the subtle difference as irrelevant for comparative studies of industrial organization between the two economies. Conventional wisdom may dictate, then, that the American approach is more conducive to scientific research which may lead to a true breakthrough in technology, whereas the Japanese approach is more consistent with applied research and product development. But whether this conventional wisdom is an empirically supportable proposition or not is yet to be seen.

[14] Such an opinion is expressed and the following counterpoint is discussed by Gary Saxonhouse (1984).

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