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# Multi-task learning and the reorganization of work: From Tayloristic to holistic organization

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# Multi-Task Learning and the Reorganization of Work. From Tayloristic to Holistic Organization

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Dennis J. Snower

April 1999

Forschungsinstitut
zur Zukunft der Arbeit
Institute for the Study
of Labor

# Multi-Task Learning and the Reorganization of Work

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April 1999

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## ABSTRACT

# Multi-Task Learning and the Reorganization of Work

## From Tayloristic to Holistic Organization*

The paper analyzes the contemporary organizational restructuring of production and work within firms. We emphasize the shift from a "Tayloristic" organization of work (characterized by significant specialization by tasks) to a "holistic" organization (featuring job rotation, integration of tasks and learning across tasks). We examine four driving forces behind this restructuring process: advances in production technologies promoting technological task complementarities, advances in information technologies promoting informational task complementarities, changes in worker preferences in favor of versatile work, and advances in human capital that make workers more versatile. Our analysis can also help explain the recent widening of wage differentials and disparities in job opportunities, not only between groups with similar characteristics, but also within these groups.

JEL Classification: J23, J24, L23, M12, O33.

Keywords: Restructuring, work organization, technological change, information flows, multi-tasking, job rotation, learning.

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## 1. Introduction

The past decade has witnessed a constellation of fundamental changes in production technologies, the nature of physical and human capital, and ideas about how to organize firms. This development has set in motion a process of restructuring the organization of work in many firms of the advanced industrialized countries. The process has been given considerable attention in the news media and in the business management and sociology literatures, [1] but has received relatively little emphasis in economic theory thus far.[2]

Until recently the evidence for this restructuring process consisted mainly of a large numbers of case studies. Over the past few years, however, a number of systematic, broad-based, empirical investigations have been completed, establishing the quantitative importance of the reorganization process. The precise nature of the process naturally varies from firm to firm, but the evidence is now sufficiently detailed[3] that it is possible to recognize some prominent central features. These features include an increased role of team work and job rotation, a reduction in the

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[1] Examples of studies where this process is described, and sometimes also recommended, are Hammer and Champy (1993), Pfeiffer (1994), Wikström and Norman (1994).

[2] Studies on the implications of this process for economic activities include Appelbaum and Bott (1994), Kremer and Maskin (1995), Mitchell, Lewin and Lowler III (1990), Levine and Tyson (1990) and Piore and Sabel (1984). For an analysis emphasizing the complementarities of different functions in the restructured firms, see Milgrom and Roberts (1990). Their focus of attention differs markedly from ours, however, in that they concentrate on changes in production technology (in terms of the rate of product improvements, processing and delivery time, setup costs, and the like), while we emphasize changes in the nature of work (multi-tasking in particular). Finally, Lindbeck and Snower (1996, 1999) examine the implications of organizational restructuring for wage inequality and centralized bargaining, respectively.

[3] Detailed studies of various European countries include the European Foundation (1997, 1998) and the OECD (1996). The reorganization of work in Nordic countries is examined by NUTEK (1996, 1999). Gallie et al. (1998) present detailed studies of the reorganization of work in the UK, emphasizing the consequences for the efficiency of work, work satisfaction and worker-employer relations. Aoki (1990, 1995) documents new forms of work organization in Japan, which in some respects pioneered the process. Osterman (1994) focuses on U.S. manufacturing establishments. Lawler, Mohrman, and Ledford (1992) examine the restructuring process in the Fortune 1000.

number of management levels, continuous learning and development of complementary skills, decentralization of responsibility within firms and direct participation of employees in decision making on multiple fronts. The empirical studies show that the restructuring process is widespread in terms of countries, sectors (encompassing services as well as manufacturing), and firms within sectors. It appears that the various features of this process have a common thread: emphasis on learning multiple tasks, the blurring down of occupational barriers, and the use of experience gained at one task to enhance performance at another task. These phenomena are the focus of our paper.

The reorganization process appears to be driven by a variety of inter-related forces. One is the introduction of computerized information and communications systems, which have provided employees with greater access to information about other employees' work within the organization and also made it easier to communicate with others. The new information technology has also given individual employees better information about customers, permitting them to respond better and more rapidly to changing customer needs. Not only have these advances facilitated the decentralization of decision making within firms; it has also enabled employees to become more involved in each other's tasks both within their own teams and in other parts of the organizations. Team work and job rotation, hence multi-tasking, have become important ways of meeting these new demands.[4]

A second driving force is the introduction of flexible machine tools and programmable equipment, which has made the capital stock more versatile, i.e. capable of performing wider spectra of tasks. As result, the workers cooperating with this capital stock are required to become more versatile as well. In the manufacturing sectors, this development has often reduced returns to scale, lowered setup and retooling costs, permitted shorter production cycles, and faster deliveries. This, in turn, has enabled firms to give customers more individualized treatment. Moreover,

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The existing evidence indicates that the restructuring of work is a quantitatively important phenomenon in many OECD countries.

[4] Supervision and management control of workers continue to be important, though there is a tendency for supervision, and related punishment and reward, to be less detailed and instead tied to post facto performance. See, for instance, Gallie et al. (1998).

greater interaction with customers often implies that employees need to exercise social, interactive skills in addition to their formal occupational requirements.

A third force, significant throughout the industrialized world, has been the steady growth of human capital per worker, generated by education systems, vocational training programs, and on-the-job training. This growth has taken the form not only of "capital deepening," in the sense that individual workers have improved their performance of particular skills; it has also involved substantial "capital widening," i.e. the ability to perform a variety of skills. This development – and especially the widening of human capital – is permitting firms to reorganize and integrate tasks along the new organizational lines.

A final driving force have been changes in worker tastes. As they acquired better general education and wider varieties of skills, they came to prefer jobs that permitted the exercise of these diverse skills. More and more employees came to resent the monotonous, fragmented jobs of traditional organizations and to prefer more varied, multi-faceted, challenging work.

An important consequence of the above changes is that occupational barriers are breaking down. The traditional organizations required employees to have highly specialized skills, appropriate for standardized production processes. Production workers required narrowly defined manual skills, sales people needed social competence, administrative personnel needed organizational and accounting skills, product designers needed creativity, and managers required judgment, initiative, leadership, and coordination skills. It is on account of this specialization that employees could readily be divided into distinct, well-defined occupations, over which the traditional distinctions between "skilled" and "unskilled" workers could be made. In this environment, relatively little attention was given to people's capacity to acquire and use multiple skills; if a person happened to have more than one occupational aptitude, he generally had to decide which particular one to use and let the rest lie fallow.

In the new types of firms emerging nowadays the traditional separation of roles tends to break down. Workers are often given responsibilities spanning more than one of the traditional occupational groupings. Greater emphasis is now also placed on continuous learning and skill development, all-round knowledge, the potential to acquire multiple skills, and the ability to learn how the experience gained from one

skill enhances another skill. The new forms of work organization are commonly designed to facilitate such “multi-task learning” in order to exploit complementarities among tasks.

It is of course not surprising that the four above-mentioned driving forces – advances in information technologies permitting integration of tasks, increased versatility of capital equipment, “widening” of human capital across tasks, and changes in workers’ preferences in favor of more varied tasks – should lead to the blurring of occupational boundaries and job rotation. But the main point of our analysis is that it provides a theoretical framework within which this association becomes straightforward. The analysis focuses attention on aspects of technological change, skill acquisition, and preference changes that have been largely ignored in the mainstream literature. Once we have developed a framework of thought that brings these elements into center-stage, the links between multi-tasking and its determinants are obvious.

The blurring of occupational barriers and the rise of multi-task learning is closely associated with the decentralization of authority within firms. The traditional pyramidal structures in service and manufacturing organizations, in particular large ones, implied that authority flowed from senior executives, down through layers of middle management, to the workers in the various functional departments. This structure is giving way to flatter organizations in which customer-oriented teams are often given greater authority. Decision making has been moved closer to the people who have the relevant information, much of which is tacit knowledge among front-line workers. The decentralization of decision making often takes the form of consultation or delegation, or both. On account of the four above-mentioned driving forces underlying the reorganization process, the decentralization of decision making often means that employees perform a wider variety of tasks with their firms. For instance, employees often share tasks within teams or combine a core job with other tasks even sometimes including some managerial or consultative functions (such as participation in so-called “quality circles” or other advisory groups).

A variety of managerial innovations – such as Total Quality Management (TQM), lean production, and just-in-time production[5] – are meant to facilitate the decentralization of decision making and learning across tasks. The move towards customer-oriented teams encourages the exploitation of complementarities among tasks, the sharing of tasks within teams, and bringing the decision-making power closer to the people who have the relevant information.

But multi-tasking, job rotation, and the blurring of occupational barriers are not the only consequences of the ongoing reorganization of work. Particularly significant is the expansion in the scope for learning and the returns from it in the new organizational environment. This aspect is our main focus of attention in this paper. The importance of learning makes the decentralization of decision making within firms yet more important, since central management has far less information about workers' learning opportunities and achievements than the workers themselves.

We will distinguish between two broad types of learning: "intra-task" and "inter-task" learning. *Intra-task learning* is learning-by-doing in the traditional sense (Arrow (1962)): the more time a worker spends at a particular task, the more skillful he becomes at performing that task, and thus the greater his productivity from this activity. *Inter-task learning*, on the other hand, arises when a worker can use the information and skills acquired at one task to improve his performance at other tasks. For instance, when a worker is involved in sales, he gains information about customer preferences that can be put to use if he is engaged in consultative groups or the provision of ancillary services to the customers (such as repairing or advice giving). Furthermore, when a worker is involved in production, he gains information about technological processes that can be useful if he contributes to organizational improvements or perhaps even product development. The business administration literature (cited above) provides a wealth of examples: information gained through marketing may be applicable to product design, information gained on the production line may be useful in product development or in training of new recruits or in devising appropriate accounting procedures, and so on.

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[5] An important objective of lean production and just-in-time production is that they expose the precise points in organizational networks where production problems, bottlenecks, and delivery delays arise, thereby enabling at these employees to tackle these deficiencies in a decentralized manner.

The tasks over which job rotation, multi-tasking, and learning occurs are here interpreted in a wide sense. They cover not only formal occupational functions, but also the exercise of social skills, communication with fellow employees and customers, collaborative skills, judgement, initiative, and creativity. In what follows, the traditional producer organizations – in which workers specialized heavily by tasks – will be called "Tayloristic."[6] The new, integrated organizations – heavily reliant on job rotation, decentralization of decision making, and inter-task learning – will be called "holistic."[7] It is important to note that our distinction between Tayloristic and holistic organizations rests on the degree of task specialization among workers, not specialization in production among firms. These two types of specialization need not proceed in tandem; quite on the contrary, many reorganized firms engage in multi-tasking while focusing more narrowly on their "core competences" in production.

There is a large literature, following the path of Adam Smith, on the determinants of specialization of work in society but little of it has focused on the features described above. Much of the recent literature on the organization of work within firms (e.g. Becker and Murphy (1992), Bolton and Dewatripont (1994), and Yang and Borland (1991)) concentrates on the returns to specialization vis-à-vis the costs of coordinating the activities of different workers. In this context, falling costs of communication (due to improvements in information technologies) lead to *greater* specialization among employees within firms, not more multi-tasking. Others (e.g. Holmstrom and Milgrom (1991)) have examined how the choice of tasks within teams depends on the remuneration system and the measurability of task performance. Rosen (1983) has shown that individuals specialize their investment in skills when there are increasing returns to human capital utilization and that non-specialization occurs when the costs of investment in different types of skills are non-separable.

None of these contributions, however, explain organizational changes associated with *reductions* in the degree of labor specialization within firms or plants, and a blurring of occupational boundaries. Our analysis does so by examining task

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[6] A term in honor of Frederick Taylor (1911), the pioneer of scientific management of firms.

[7] In making this distinction, our aim is to focus on broad, overall trends in the organization of work. There are of course counterexamples, involving increasing task specialization, such as much research and much medical and legal practice.

coordination and specialization on an *intra-personal* level (one individual performing one or more tasks) rather than on an *inter-personal level* (a group of people performing a broader or narrower range of tasks). Furthermore, our analysis examines the determinants of firms' incentives to restructure their organizations of work in favor of multi-tasking or job rotation.

The rest of the paper is organized as follows. Section 2 analyzes the trade-off between the returns from specializing at a task and the returns from exploiting the complementarities between tasks. It embeds this analysis in a model of a profit maximizing firm. Section 3 examines how such a firm decides on its organization of production and work. In this context, Section 4 investigates how the restructuring process is driven by changes in physical capital, information technology, workers' preferences, and human capital. Finally, Section 5 concludes.

## 2. The Firm's Decision Making Problem

In deciding whether workers are to specialize or perform multiple tasks,[8] employers face a tradeoff between two sets of returns: (i) "returns from specialization" whereby a worker's productivity at a particular task increases with his exposure to that task, and (ii) "returns from task complementarities" whereby his activity at one task raises his productivity at another task.

The returns to specialization may be viewed as the result of intra-task learning, and are well-known. The returns from task complementarities, on the other hand, have received much less attention thus far. They may be divided into what we will call "technological" and "informational" task complementarities.

The *technological task complementarities* are captured by the cross-partial derivatives between different types of labor in the production function: just as labor and capital may be complementary in the production process, so different occupational types of labor may be complementary as well. To take a trivial example, the productivity of managers is enhanced by the services of their secretaries, and the managers do not themselves have to perform secretarial tasks for this complementarity to arise.

The *informational task complementarities* are the outcome of inter-task learning. Analytically, these complementarities may be captured by letting, a worker's human capital at one task depend on his activity at other tasks.[9] For example, a worker within a team may become more skillful in a specific task when he learns related tasks within his team. His ability to perform a specific task may also be enhanced by learning tasks within quite different parts of the firms.

Clearly, both the returns to specialization and the informational task complementarities manifest themselves only with the passage of time. For simplicity, however, our analysis covers only a single time period, and thus the length of this period must be taken as sufficiently long for these returns to be able to manifest themselves. To clarify concretely how informational task complementarities can arise, the appendix presents a simple model of such complementarities and indicates how they may interact with the returns to specialization and the technological task complementarities. But whereas the appendix describes particular tasks (production and sales), we here portray the tasks in full generality. Furthermore, whereas in the appendix the information gathering process runs in one direction (from sales to production, but not the other way around), we assume here that the informational task complementarity runs in both directions: time spent at task 1 enhances a worker's endowment at task 2, and vice versa.

Consider a firm that produces its output through two tasks, 1 and 2. (Whereas in the appendix these tasks are identified as production and sales, they could cover a vast array of complementary tasks, such as different types of production work or participation in quality circles, the supervision and training, etc.) The firm's employees can be divided into two homogeneous groups: "type-1 workers," whose skills give them a comparative advantage at task 1, and "type-2 workers," with a comparative advantage at task 2.

Moreover, to bring into sharp focus the role that each worker's returns to specialization and returns to informational task complementarities play in the

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[8]Note that the gains from multi-tasking by a worker are analogous to the economies of scope arising when a firm produces several different products (See Baumol, Panzer, and Willig (1982).)

[9] Thereby the informational task complementarities give leverage to the technological task complementarities.

production process, we will view these returns as components of the worker's "labor endowment" (or human capital). Let $e_1$ and $e_2$ be the labor endowment for each type-1 worker at tasks 1 and 2, respectively; and let $E_1$ and $E_2$ be the labor endowment of each type-2 worker at these tasks. We assume that $(e_1 / e_2) > (E_1 / E_2)$, so that type-1 workers have a comparative advantage at task 1 (and conversely for type-2 workers).

Let $\tau$ be the fraction of each type-1 worker's available time devoted to task 1, and 1-$\tau$ be the remaining fraction devoted to task 2.[10] Furthermore, let (1-$T$) and $T$ be the type-2 worker's distribution of time between tasks 1 and 2, respectively. Let $n$ and $N$ be the number of type-1 and type-2 workers employed, respectively. Then the total labor services in efficiency units devoted to tasks 1 and 2 become

$$\begin{aligned} \lambda_1 &= e_1 \cdot \tau \cdot n + E_1 \cdot (1 - \mathrm{T}) \cdot N \\ \lambda_2 &= e_2 \cdot (1 - \tau) \cdot n + E_2 \cdot \mathrm{T} \cdot N \end{aligned} \tag{1}$$

The labor endowments depend on the returns to specialization and the returns to informational task complementarities. Although these returns may not be straightforward to identify separately in practice, it is nevertheless convenient for our analysis to represent them by separate variables, which are determinants of the labor endowments. Specifically, let $s_i$ and $S_i$, $i$=1,2, be the returns to specialization at task $i$ for the type-1 and type-2 workers, respectively. Let $c_i$ and $C_i$, $i$=1,2, be the informational task complementarities running to task $i$ for the type-1 and type-2 workers, respectively (i.e. the increase in the workers' productivity at task $i$ achieved by gaining information about the other task). Then we express the labor endowments of the type-1 worker at tasks 1 and 2, respectively, as

$$e_1 = \xi_1(s_1, c_1) \text{ and } e_2 = \xi_2(s_2, c_2) \tag{2a}$$

and the corresponding labor endowments of the type-2 worker as

$$E_1 = \Xi_1(S_1, C_1) \text{ and } E_2 = \Xi_2(S_2, C_2) \tag{2b}$$

where $(\partial\xi_j / \partial s_i), (\partial\xi_j / \partial c_i) > 0$, $(\partial\Xi_j / \partial S_i), (\partial\Xi_j / \partial C_i) > 0$, for $i, j$=1,2.

The return to specialization at each task, arising from intra-task learning, depends positively on the fraction of time devoted to that task. Thus, for the type-1 worker:

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[10] It is however worth noting that in practice most output require many tasks and multi-taskers usually perform only a few of these tasks in varying combinations.

$$s_1 = s_1(\tau) \text{ and } s_2 = s_2(1-\tau), \quad s_1', s_2' > 0 \tag{3a}$$

and similarly for each type-2 worker:

$$S_1 = S_1(1-\mathrm{T}) \text{ and } S_2 = S_2(\mathrm{T}), \quad S_1', S_2' > 0 \tag{3b}$$

Furthermore, the greater the fraction of a worker's time is devoted to the task *i*, the more information he gains about this task and consequently the more productive he becomes at task *j*, $j \neq i$. Thus the informational task complementarity, resulting from the inter-task learning of each type-1 worker, may be expressed as

$$c_1 = c_1(1-\tau) \text{ and } c_2 = c_2(\tau), \quad c_1', c_2' > 0 \tag{4a}$$

Specifically, $c_1$ is the worker's ability to increase his productivity at task 1 through time spent $(1-\tau)$ on task 2, and $c_2$ is his ability to increase his productivity at task 2 through time spent $(\tau)$ on task 1. Along the same lines, the informational task complementarity arising from the inter-task learning of each type-2 worker is

$$C_1 = C_1(\mathrm{T}) \text{ and } C_2 = C_2(1-\mathrm{T}), \quad C_1', C_2' > 0 \tag{4b}$$

In sum, we may think of the time allocations $\tau$ and $T$ as generating human capital in the type-1 and type-2 workers (respectively), and this human capital contributes to the workers' labor endowments via the returns to specialization and the informational task complementarities.

Substituting the returns to specialization ((3a) and (3b)) and the informational task complementarities ((4a) and (4b)) into the labor endowment functions ((2a) and (2b)), and substituting these labor endowment functions into the labor services (1), we obtain these services solely as functions of the time allocations across tasks and the number of workers employed:

$$\begin{aligned}
\lambda_1 &= e_1 \cdot \tau \cdot n + E_1 \cdot (1-\mathrm{T}) \cdot N \\
&= \xi_1\big(s_1(\tau), c_1(1-\tau)\big) \cdot \tau \cdot n + \Xi_1\big(S_1(1-\mathrm{T}), C_1(\mathrm{T})\big) \cdot (1-\mathrm{T}) \cdot N \\
&= \lambda_1(\tau, \mathrm{T}; n, N)
\end{aligned}$$

$$\begin{aligned}
\lambda_2 &= e_2 \cdot (1-\tau) \cdot n + E_2 \cdot \mathrm{T} \cdot N \\
&= \xi_2\big(s_2(1-\tau), c_2(\tau)\big) \cdot (1-\tau) \cdot n + \Xi_2\big(S_2(\mathrm{T}), C_2(1-\mathrm{T})\big) \cdot \mathrm{T} \cdot N \\
&= \lambda_2(\tau, \mathrm{T}; n, N)
\end{aligned}$$

Observe that when a type-1 worker increases the time ($\tau$) spent at task 1, there are three effects on type-1 labor services ($\lambda_1$): a direct, positive effect in terms of labor time ($\tau \cdot n$ increases); a positive effect via the returns to specialization ($s_1(\tau)$

increases); and a negative effect via the returns from informational complementarities ($c_1(1-\tau)$ falls). But although the net influence on labor services is thus ambiguous in general, we assume that

$$\frac{\partial\lambda_1}{\partial\tau},\frac{\partial\lambda_2}{\partial(1-\tau)}>0 \text{ and } \frac{\partial\lambda_1}{\partial(1-\mathrm{T})},\frac{\partial\lambda_2}{\partial\mathrm{T}}>0,\ \frac{\partial\lambda_2}{\partial\mathrm{T}}>0 \tag{5}$$

i.e. an increase in the time spent at task 1 increases the type-1 labor services, so that the two positive effects above dominate the negative effect. And similarly for the other task and for the type-2 labor services.

The firm's real revenue is a function of the labor services, $\lambda_1$ and $\lambda_2$:

$$r = f\left(\lambda_1(\tau,\mathrm{T};n,N),\lambda_2(\tau,\mathrm{T};n,N)\right) \tag{6}$$

where $f_i > 0$, $f_{ii} < 0$ ($i$ = 1,2) and $f_{ij} > 0$ ($i$ = 1,2 and $j \neq i$). The technological task complementarities may be depicted in terms of the positive cross-partial derivatives: $f_{ij}$, $i$ = 1,2 and $j \neq i$.

For expositional simplicity, but without substantive loss of generality, we assume that the comparative advantages of the type-1 and type-2 workers at the two tasks are symmetric. Specifically, for any positive real numbers $x$, $0 \le x \le 1$, we require $s_1(x) = S_2(x)$, $s_2(x) = S_1(x)$, $c_1(x) = C_2(x)$, and $c_2(x) = C_1(x)$, so that the returns to specialization of type-1 worker at task 1 are identical to the returns to specialization of type-2 worker at task 2, and similarly for the type-1 worker at task 2 and the type-2 worker at task 1. In addition, we assume that the labor services $\lambda_1$ and $\lambda_2$ enter the revenue function symmetrically, i.e. for any positive number $x$, we require that $f(x,\lambda_2) = f(\lambda_1,x)$ for $\lambda_1 = \lambda_2$.

Let the firm's real labor costs be $wn + WN$, where $w$ and $W$ are the real wages of the type-1 and type-2 workers, respectively. For simplicity, but without any substantive loss of generality, we assume that these wages are the reservation wages of these workers (i.e. the wages that make them indifferent between employment and leisure). Furthermore, we suppose that the workers have preferences regarding the organization of work. If workers prefer specialized to versatile work, then their reservation wage achieves a maximum at $\tau$ = 1/2 (when they do devote equal amounts of time to both tasks); if they prefer versatile work, then their reservation wage attains a minimum at $\tau$ = 1/2. So, provided that the wage depends positively on the

reservation wage, we specify that $w = w(\tau)$, $w'(1/2) = 0$; and if the workers prefer specialization, then $w'' < 0$, whereas if they prefer versatility, then $w'' > 0$.

The firm's profit is

$$\pi(\tau, \mathrm{T}, n, N) = f\left(\lambda_1(\tau, \mathrm{T}; n, N), \lambda_2(\tau, \mathrm{T}; n, N)\right) - w(\tau)n - W(\mathrm{T})N \qquad (7)$$

On account of the symmetry assumptions above, the organization will distribute the type-1 and type-2 workers' time equally across the two tasks when equal numbers of these workers are employed. Thus it is sufficient to examine the organization's profit-maximizing decision with respect to $\tau$ alone, focusing our analysis entirely on the type-1 workers.

The firm's aim is to maximize its profit with respect to the number of employees ($n$ and $N$) and the organization of work ($\tau$ and $T$). We now proceed to examine the determinants of the Tayloristic versus holistic organization of work.

## 3. The Tayloristic versus Holistic Organization of Work

Under the Tayloristic organization of work, type-1 workers specialize in task 1, so that $\tau$=1; whereas under the holistic work organization, the worker performs both tasks,[11]so that $0<\tau<1$.[12]

The following proposition shows how the profit-maximizing firm chooses its organization of work:[13]

***Proposition 1****: Given the profit function* $\pi = \pi(\tau, \mathrm{T}, n, N)$*, the profit-maximizing organization of work is holistic (0 < τ* < 1) whenever the following condition is fulfilled:*

$$\frac{\partial \pi}{\partial \tau} = 0 \text{ in the domain } 0 < \tau < 1, \text{ and}$$
$$\frac{\partial^2 \pi}{\partial \tau^2} < 0 \text{ in the neighborhood of } \frac{\partial \pi}{\partial \tau} = 0$$

[11]Unless the worker is perfectly versatile, the two tasks however will not be performed at equal levels.

[12] The same holds for type-2 workers, $T$=1 under Tayloristic organization and $0<T<1$ under holistic organization; but, as noted, the analysis below need only focus on type-1 workers.

*and the profit-maximizing organization of work is Tayloristic ($\tau* = 1$) whenever this condition is violated.*

The intuition is straightforward: Since workers specialize by task in a Tayloristic organization, the profit-maximizing allocation of time across tasks must lie at a corner point. But since workers in a holistic organization do not specialize in this way, the profit-maximizing allocation of time must lie in the interior of the feasible set.

We now proceed to examine various driving factors influencing a firm's choice of organizational form. The marginal profit from a change in the organization of work is

$$\frac{\partial \pi}{\partial \tau} = MR - MC^o - MC^w \tag{8}$$

where $$MR = f_1 \cdot \frac{\partial \lambda_1}{\partial \tau}, \quad MC^0 = -f_2 \cdot \frac{\partial \lambda_2}{\partial \tau}, \quad MC^w = \frac{dw}{d\tau} n$$

*MR* is the marginal revenue with respect to $\tau$: an increase in the fraction of time at task 1 raises the firm's revenue by increasing the labor services devoted to task 1. $MC^o$ is the marginal opportunity cost of task 1 in terms of task 2: an increase in the fraction of time at task 1 diminishes the firm's revenue by reducing the labor services devoted to task 2. And $MC^w$ is the marginal cost due to changes in the wage rate that result from changes in the time allocation $\tau$. These marginal revenue and cost terms are illustrated in Figures 1.

The change in the marginal profit is

$$\frac{\partial^2 \pi}{\partial \tau^2} = \frac{\partial MR}{\partial \tau} - \frac{\partial MC^o}{\partial \tau} - \frac{\partial MC^w}{\partial \tau} \tag{9}$$

where $$\frac{\partial MR}{\partial \tau} = \left[ \left( f_{11} \frac{\partial \lambda_1}{\partial \tau} + f_{12} \frac{\partial \lambda_2}{\partial \tau} \right) \frac{\partial \lambda_1}{\partial \tau} + f_1 \frac{\partial^2 \lambda_1}{\partial \tau^2} \right],$$

$$\frac{\partial MC^0}{\partial \tau} = -\left[ \left( f_{21} \frac{\partial \lambda_1}{\partial \tau} + f_{22} \frac{\partial \lambda_2}{\partial \tau} \right) \frac{\partial \lambda_2}{\partial \tau} + f_2 \frac{\partial^2 \lambda_2}{\partial \tau^2} \right], \text{ and}$$

$$\frac{\partial MC^w}{\partial \tau} = \frac{d^2 w}{d\tau^2} n$$

To fix ideas, we assume that the tasks are technological complements:

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[13]Our assumption that $(\partial \lambda_1 / \partial \tau), (\partial \lambda_2 / \partial (1-\tau)) > 0$ ensures that the optimum is

$$f_{12} = f_{21} > 0.$$

Moreover, since $(\partial\lambda_1 / \partial\tau) > 0$ and $(\partial\lambda_2 / \partial\tau) < 0$ (by (5)), and since $f_{11} < 0$, the first term of $(\partial MR / \partial\tau)$ is negative. Thus the sign of $(\partial MR / \partial\tau)$ depends critically on $f_1\left(\partial^2\lambda_1 / \partial\tau^2\right)$, where $f_1 > 0$ and $\left(\partial^2\lambda_1 / \partial\tau^2\right)$ measures how fast the type-1 labor service declines as $\tau$ rises.

The term $\left(\partial^2\lambda_1 / \partial\tau^2\right)$ depends on the returns to specialization relative to the returns to informational task complementarities. In particular, recall that raising $\tau$ increases the opportunity to reap the returns from specialization at task 1 but reduces the opportunity to reap the return from using information gained at task 1 to enhance his productivity at task 2. Thus, the more rapidly the return from specialization falls relative to the task-1 return from the informational task complementarity (productivity at task 1 gained from information at task 2), the more rapidly will the type-1 labor service decline as $\tau$ rises. Thus the lower is $f_1\left(\partial^2\lambda_1 / \partial\tau^2\right)$) and the more rapidly the marginal revenue declines with respect to $\tau$ (i.e. the lower is $\left(\partial MR / \partial\tau\right)$). As Figures 1 imply, the more rapidly the marginal revenue declines, the more attractive it eventually becomes for the firm to adopt a holistic organization of work.

In our expression for the change in the marginal opportunity cost of task 1 in terms of task 2, $\dfrac{\partial MC^o}{\partial\tau} = -\left[\left(f_{21}\dfrac{\partial\lambda_1}{\partial\tau} + f_{22}\dfrac{\partial\lambda_2}{\partial\tau}\right)\dfrac{\partial\lambda_2}{\partial\tau} + f_2\dfrac{\partial^2\lambda_2}{\partial\tau^2}\right]$, the first term of $(\partial MC^o / \partial\tau)$ is positive. (The reason is that $(\partial\lambda_1 / \partial\tau) > 0$, $(\partial\lambda_2 / \partial\tau) < 0$ (by (5)) and since $f_{22} < 0$, and $f_{21} > 0$.) Thus the sign of $(\partial MC^o / \partial\tau)$ depends critically on $f_2\left(\partial^2\lambda_2 / \partial\tau^2\right)$, where $f_2>0$ and $\left(\partial^2\lambda_2 / \partial\tau^2\right)$ indicates how fast the type-2 labor service declines as $\tau$ rises. In particular, $\left(\partial^2\lambda_2 / \partial\tau^2\right)$ will be lower the faster the rate at which the task-2 return to specialization falls relative to the task-2 return to the informational task complementarity (productivity at task 2 gained from information at task 1). Thus the faster will the marginal cost $MC^o$ rise with respect to $\tau$. Then, as Figures 1 imply, the firm's eventually gains an incentive to adopt a holistic work organization.

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unique.

Finally, the change in the marginal cost in terms of the wage $(\partial MC^{w} / \partial \tau)$ depends on the worker's preferences regarding work versatility. The more the worker prefers versatile work over task specialization, the greater is $\frac{d^2 w}{d\tau^2}$, and thus the faster will the marginal cost $MC^{w}$ rise with respect to $\tau$. Consequently, as indicated in Figures 1, the more worthwhile it eventually is for the firm to adopt a holistic organizational form.

In Figure 1a we assume that (i) the returns to specialization (at each task) increase sufficiently fast relative to the returns from informational task complementarities and (ii) the type-1 workers have a sufficiently strong preference for specialized work, so that the marginal revenue rises with $\tau$ ($(\partial MR / \partial \tau) > 0$) and the total marginal cost to declines with $\tau$ ($(\partial MC / \partial \tau) < 0$). Here work is organized along Tayloristic lines.[14]

In Figure 1b, by contrast, we assume that (i) the returns from the informational task complementarity (at each task) increases sufficiently fast relative to the associated returns to specialization and (ii) the type-1 workers have a sufficiently strong preference for versatile work, so that the marginal revenue falls with $\tau$ and the total marginal cost to rises with $\tau$. Since the intersection of the marginal revenue and marginal cost curves occurs at $\tau^* < 1$ in the figure, the organization of work is holistic.

## 4. The Restructuring Process

In this context we are now able to analyze the determinants of the restructuring process whereby Tayloristic organizations turn into holistic ones. We conceive of this process as being driven by four major forces: (i) changes in physical capital, (ii) changes in information technology, (iii) changes in workers' preferences, and (iv) changes in human capital. [15]

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[14]Note that under a Tayloristic work organization $\tau$ must be equal to unity, rather than zero, since type-1 workers have a comparative advantage in task 1.

[15]A fifth force, lying beyond the scope of our analysis, is a trend change in consumer preferences in favor of more highly differentiated products. This favors holistic organizations over Tayloristic ones since holistic organizations usually permit closer interactions between their employees and the customers and enable the employees to

Only certain types of *changes in physical capital* give firms an incentive to adopt holistic organizational forms. In the traditional literature on capital formation, the productivity of capital and the complementarity between capital and labor (or between capital and other factors of production) is often the center of attention. Our analysis focuses attention on a different characteristic of physical capital, namely, the associated technological task complementarities. In the model above, these complementarities are captured by the cross-partial $f_{12} = f_{21}$ of the revenue function.

We argue that whereas the prominent changes in physical capital occurring in the first half of the twentieth century favored Tayloristic organizations, the more recent changes (occurring over the past decade or two) are strongly biased in favor of holistic organizations. The big breakthroughs in mass production and mass marketing that were the hallmark of technological progress in the first part of this century - such as assembly lines, specialized manufacturing equipment, hierarchical organizations within firms – accentuated returns to scale at specialized tasks. In terms of our analysis, they can be viewed as being associated with large returns to specialization and low technological task complementarities (i.e. low inter-task cross partials such as $f_{12} = f_{21}$).

However, the salient recent advances in physical capital – such as the adoption of multi-purpose machine tools and programmable manufacturing equipment – have increased the versatility of machines across tasks and therefore facilitate the exploitation of inter-task complementarities. For instance, recent technical changes have enabled rapid retooling and reprogramming of machines in many sectors, to permit faster production responses to changes in customer demands, thereby making it easier to exploit complementarities between production and sales tasks. In short, as machines have become more versatile, so labor has been enabled to become more versatile as well. These advances may be expected to increase the technological task complementarities, i.e. raise the inter-task cross partials such as $f_{12} = f_{21}$.

By equation (9), an increase in the cross partial $f_{12} = f_{21}$ makes the marginal revenue fall more rapidly with respect to the time allocation $\tau$ (i.e. reduces $(\partial MR / \partial \tau)$) and makes the marginal opportunity cost of task 1 in terms of task 2 rise

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use their detailed information about customer preferences to affect their performance of other tasks.

more rapidly with respect to $\tau$ (i.e. increases $\left(\partial MC^o / \partial\tau\right)$). Through these channels, the above changes in physical capital reduce the value of $\left(\partial^2\pi / \partial\tau^2\right)$.

To highlight the role of changes in physical capital that increase the value $f_{12}$, we rewrite equation (9) as follows:

$$\frac{\partial^2\pi}{\partial\tau^2} < 0 \quad \Leftrightarrow$$

$$f_{12} > \frac{1}{\frac{\partial\lambda_1}{\partial\tau}\frac{\partial\lambda_2}{\partial\tau}}\left[-f_{11}\left(\frac{\partial\lambda_1}{\partial\tau}\right)^2 - f_1\frac{\partial^2\lambda_1}{\partial\tau^2} - f_{22}\left(\frac{\partial\lambda_2}{\partial\tau}\right)^2 - f_2\frac{\partial^2\lambda_2}{\partial\tau^2} + \frac{\partial^2 w}{\partial\tau^2}n\right]$$

Thus a rise in $f_{12}$ reduces the second derivative of the profit function. If this change is sufficiently large to ensure that the above inequality holds, the firm may choose a holistic organization of work.

Furthermore, we argue that recent *changes in information technologies* – such as the proliferation of information gathering processes and introduction of computerized production, design, and product development – also favor holistic organizations. The reason is that these advances provide rapid and cheap access to information; thereby they encourage the exercise of multiple skills over multiple tasks and provide scope for inter-task learning. In this respect, they may be expected to augment informational task complementarities relative to the associated returns to specialization.

In the context of our model, an increase in informational task complementarities may be represented by an increase in $(\partial\xi_1 / \partial c_1)$ and $(\partial\xi_2 / \partial c_2)$, and possibly also by an increase in $(\partial^2\xi_1 / \partial c_1^{\,2})$ and $(\partial^2\xi_2 / \partial c_2^{\,2})$. These changes have the following effects on the relation between the type-1 and type-2 labor services and the time allocation between tasks: They reduce $\frac{\partial\lambda_1}{\partial\tau} = -\frac{\partial\xi_1}{\partial c_1}\tau n + e_1 n$ and $\frac{\partial\lambda_2}{\partial\tau} = -\frac{\partial\xi_2}{\partial c_2}(1-\tau)n - e_2 n$, and they also reduce $\frac{\partial^2\lambda_1}{\partial\tau^2} = -\frac{\partial^2\xi_1}{\partial c_1^{\,2}}\tau n + 2\frac{\partial\xi_1}{\partial c_1}n$ and $\frac{\partial^2\lambda_2}{\partial\tau^2} = -\frac{\partial^2\xi_2}{\partial c_2^{\,2}}(1-\tau)n$. By (9), these changes make the marginal revenue fall more rapidly with respect to the time allocation $\tau$ and make the marginal opportunity cost of task 1 in terms of task 2 rise more rapidly with respect to $\tau$, thus reducing the value of

$\left(\partial^2\pi / \partial\tau^2\right)$. As noted, if this value becomes negative, the firm may choose a holistic work organization.

To clarify the influence of the above changes in information technologies on work organization, let us simply suppose that $(\partial^2\lambda_1 / \partial\tau^2) = (\partial^2\lambda_2 / \partial\tau^2)$. Then equation (9) may be rewritten as follows:

$$\frac{\partial^2\pi}{\partial\tau^2} < 0 \quad \Leftrightarrow$$

$$\frac{\partial^2\lambda_i}{\partial\tau^2} < \frac{1}{f_1 + f_2}\left[-\left(f_{11}\frac{\partial\lambda_1}{\partial\tau} + f_{12}\frac{\partial\lambda_2}{\partial\tau}\right)\frac{\partial\lambda_1}{\partial\tau} - \left(f_{21}\frac{\partial\lambda_1}{\partial\tau} + f_{22}\frac{\partial\lambda_2}{\partial\tau}\right)\frac{\partial\lambda_2}{\partial\tau} + \frac{\partial^2 w}{\partial\tau^2}n\right]$$

for $i$ = 1,2. Consequently, a change in information technology that reduces the value of $(\partial^2\lambda_i / \partial\tau^2)$ will reduce the second derivative of the profit function. If this change is sufficiently large to ensure that the above inequality holds, a holistic organizational form will be chosen.

Along the same lines, *changes in worker preferences* in favor of versatile work increase the value of $(\partial^2 w / \partial\tau^2)$, and thereby increase the marginal cost $\left(\partial MC^w / \partial\tau\right)$ and thereby also reduce $\left(\partial^2\pi / \partial\tau^2\right)$. There is plentiful evidence in the sociology and business literatures (referenced above) that workers have a growing need to be stimulated at work. Since holistic work tends to be more varied, creative, and challenging than the narrowly defined Tayloristic jobs, these workers are likely to be progressively less inclined to work for Tayloristic organizations than for holistic ones. In the context of our analysis, by equation (9), it is clear that if $(\partial^2 w / \partial\tau^2)$ is large enough so that

$$\frac{d^2 w}{d\tau^2} > \frac{1}{n}\left[\left(f_{11}\frac{\partial\lambda_1}{\partial\tau} + f_{12}\frac{\partial\lambda_2}{\partial\tau}\right)\frac{\partial\lambda_1}{\partial\tau} + f_1\frac{\partial^2\lambda_1}{\partial\tau^2}\right] + \frac{1}{n}\left[\left(f_{21}\frac{\partial\lambda_1}{\partial\tau} + f_{22}\frac{\partial\lambda_2}{\partial\tau}\right)\frac{\partial\lambda_2}{\partial\tau} + f_2\frac{\partial^2\lambda_2}{\partial\tau^2}\right]$$

then $\left(\partial^2\pi / \partial\tau^2\right)$ < 0, and the firm may prefer a holistic organizational form.

Finally, we maintain that the steady *rise of human capital*, produced largely by education and training systems, has favored holistic organizations as well. In the traditional literature, the aspects of human capital growth that have been emphasized are those relating to the productivity of labor and the transferability of labor across firms (“general” versus “firm-specific” skills). Our analysis highlights a different

aspect of human capital growth, namely, the increased ability to perform multiple tasks.

This development plays a different role in organizational change than the changes discussed above. As noted, the changes in physical capital, information technologies, and worker preferences analyzed above all serve to reduce the value of $\left(\partial^2\pi / \partial\tau^2\right)$, ultimately making it negative. But, as Proposition 1 indicates, a negative value of $\left(\partial^2\pi / \partial\tau^2\right)$ is not sufficient to make a holistic organization more profitable than a Tayloristic one. What is required, in addition, is that $\left(\partial\pi / \partial\tau\right) = 0$ for $0 < \tau < 1$. It is this latter aspect that is promoted by the "widening" of human capital.

Specifically, if $\left(\partial^2\pi / \partial\tau^2\right) < 0$, then *changes in human capital* that enable workers to do more versatile work serve to move the profit maximizing time allocation $\tau^*$ towards (1/2), in the interior of the feasible region $0 \le \tau \le 1$. (Under the symmetry conditions above, complete versatility implies that $\tau^* = ½$ when the second-order condition $\left(\partial^2\pi / \partial\tau^2\right) < 0$ is satisfied.) In other words, this development favors holistic work organization by increasing the rate at which the marginal opportunity cost of task 1 (in terms of task 2) rises with $\tau$.

The profit-maximizing responses in work organization to the above changes are summarized in the following proposition:

***Proposition 2****: In response to sufficiently large*

(i) *changes in production technologies that increase the technological task complementarities ($f_{ij}$, $i \neq j$),*

(ii) *changes in information technologies that increase the informational task complementarities (reducing $(\partial^2\lambda_1 / \partial\tau^2)$),*

(iii) *changes in worker preferences in favor of versatile work (increasing $(\partial^2 w / \partial\tau^2)$), and*

(iv) *changes in human capital that increase worker versatility,*

*Tayloristic organizations gain the incentive to restructure into holistic organizations.*

These profit-maximizing responses follow directly from our framework of analysis, which we believe indicates the usefulness of this framework.

Our analysis also has implications for whether the restructuring process is continuous or discontinuous:

***Proposition 3****: If the switch from a Tayloristic to a holistic organization of work is induced by changes in human capital that make workers more versatile, then the restructuring process will be smooth. If, on the other hand, the switch is induced by (i) increases in technological task complementarities, (ii) increases in informational task complementarities or (iii) greater preferences for versatile work, then the restructuring process may be discontinuous.*

To see this, observe that if it is the improvements in information and production technology that induce the switch, then it is the change in the sign of $(\partial^2\pi / \partial\tau^2)$ that is responsible for the switch. Specifically, if $(\partial^2\pi / \partial\tau^2) > 0$ in the original equilibrium whereas $(\partial^2\pi / \partial\tau^2) < 0$ and $(\partial\pi / \partial\tau) = 0$ at $0<\tau<1$ in the new equilibrium, then the profit maximizing number of hours changes discontinuously from complete specialization to multi-tasking. This phenomenon is illustrated in Figure 2a, where the initial profit function $\pi_1$ (for which $(\partial^2\pi / \partial\tau^2) > 0$) is maximized at the Tayloristic point $E_1$ (where $\tau^* = 1$) and the new profit function $\pi_2$ (for which $(\partial^2\pi / \partial\tau^2) < 0$) is maximized at the holistic point $E_2$ (where $0 < \tau^* < 1$).

On the other hand, if $(\partial^2\pi / \partial\tau^2) < 0$ and the profit maximizing time allocation is initially at $\tau^* = 1$, then changes in human capital that make workers more versatile will move the profit maximizing time allocation gradually into the interior of the domain $0 \le \tau \le 1$. This change is continuous, as pictured in Figure 2b. Here the initial profit function, denoted by $\pi_a$, achieves a maximum at the Tayloristic point $E_a$ (where $\tau^* = 1$) and the new profit function $\pi_b$ is maximized at the holistic point $E_b$ (where $0 < \tau^* < 1$).

## 5. Concluding remarks

This paper has analyzed the role of multi-tasking, intra-task learning, and inter-task learning in the contemporary reorganization of work. We have focused on four driving forces behind the reorganization process: advances in production technologies promoting technological task complementarities, advances in information technological promoting informational task complementarities, changes in worker preferences in favor of versatile work, and advances in human capital that make workers more versatile.

As mentioned in the introduction, the business and management literature indicates that a dramatic and broadly based process of organizational change – involving a move towards multi-tasking, job rotation, and inter-task learning – has been underway for some time, and is likely to continue. Furthermore, as noted, recent empirical studies suggest that reorganization of work is a quantitatively significant phenomenon. But while this reorganization has been much discussed in an informal, descriptive way, there has been little if any theoretical framework to analyze this process. The main ambition of this paper has been to develop such a framework. Once this has been done, the connections between the reorganization of work and its main determinants (recent changes in physical capital, information technologies, human capital, and preferences) look intuitively obvious.

Our analysis may also be viewed as a contribution to the contemporary debate on the sources of the increased dispersion of wages and job opportunities in the US and Europe. The dominant hypotheses thus far have been that these phenomena are the outcome of (i) skill-biased international trade flows, [16] (ii) skill-biased technological change, [17] and (iii) deficient education and training relative to the demand for skilled labor. [18]

Our theory is complementary with the hypothesis resting on international trade, since the expansion of trade has enabled an increasing number of firms in the advanced industrialized countries to shift to products and production processes

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[16]See, for example, Leamer (1994, 1995) and Sachs and Schatz (1994).
[17]See, for example, Berman, Bound and Grilliches (1993), Bound and Johnson (1992), Krueger (1993), Machin (1994), and Mincer (1989, 1991).
[18]See, for example, Mincer (1991), Levy and Murname (1992), and Katz, Loveman, and Blanchflower (1992), among others.

requiring holistic organization, while contracting out the routine, assembly line work to other countries. Our theory is also complementary to the hypotheses resting on technological change, education and training. But it goes further than these hypotheses in explaining wage and employment dispersion, since our analysis specifies *how* changes in production and information technologies and *how* education and training may be expected to affect the dispersion of wages and employment opportunities in the context of the reorganization of work.

Finally, the three hypotheses above explain neither the widening inequality of wages *within* education, occupation, and job tenure groups in the US and the UK, nor the widening inequality of employment opportunities within these groups in various countries on the European continent. Our analysis offers an explanation for these phenomena: People within particular education, occupation, and job tenure groups are likely to vary considerably in terms of their social competence, judgment, and ability to perform multiple tasks. Thus, in countries such as the US and the UK, where real wages often respond flexibly to changes in labor demands and supplies, the move from Tayloristic to holistic organizations of work may lead to widening wage dispersion of wages within these groups. By contrast, in several European countries where real wages are more rigid, the reorganization of firms may give rise to a widening dispersion of employment opportunities among these groups, for a given distribution of abilities.

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## *Appendix*

The aim of this appendix is to construct a simple, illustrative model of informational task complementarities, indicating how they may arise and how they relate to the returns of specialization and the technological task complementarities. Specifically, the model focuses on an informational structure that generates a trade-off between returns to specialization and returns to informational task complementarities.

Suppose that each worker performs just two tasks, which we may think of as "production" and "sales," and where the informational task complementarities run in just one direction (from "sales" to "production"). Let $\tau$ be the fraction of time the worker devotes to production, and let (1-$\tau$) be the remaining fraction devoted to sales. Suppose that the output is nondurable. The amount of output produced per period depends on (i) the fraction of time $\tau$ the worker devotes to production and (ii) his productivity $s_\pi$ at the production task (where the subscript *p* denotes production):

$$q = g(\tau s_\pi), \quad g' > 0 \tag{A1}$$

where $\tau s_\pi$ is labor in efficiency units. Suppose that the productivity $s_\pi$ depends solely on returns to specialization, so that

$$s_\pi = s_\pi(\tau), \quad s_\pi' > 0 \tag{A2}$$

Similarly, the greater the fraction of time (1-$\tau$) the worker devotes to sales, the greater his productivity at the sales task:

$$s_\sigma = s_\sigma(1-\tau), \quad s_\sigma' > 0 \tag{A3}$$

where the subscript *s* denotes sales.

The firm's revenue is $R = py$, where $p$ is the price and $y$ is the quantity sold. The demand for the good depends inversely on the price ($p$), positively on labor services devoted to sales, $(1-\tau)s_\sigma$, and negatively on the divergence between the product quality and customers' most preferred quality (measured by the variable *d*, to be defined precisely below):

$$y = y(p, (1-\tau)s_\sigma, \delta), \quad y_1 < 0, y_2 > 0, y_3 < 0 \tag{A4}$$

Suppose that the good produced is one of an infinite variety of potential goods, whose differences may be represented by a continuum of product qualities. All customers are assumed to have the same product preferences, which are ordered

around the circumference of a circle, in the spirit of Vickery (1964). On this circle, pictured in Fig. A, there exists one point ($q^*$) which is most preferred, and customers prefer qualities that are closer to $q^*$ on the circle to ones that are further away.

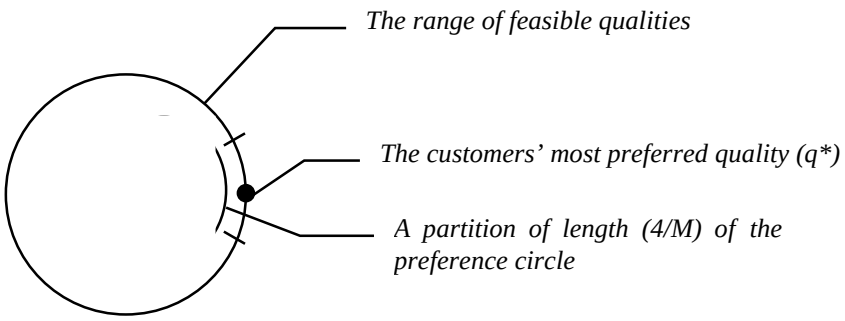


Figure A: The Information Gathering Process

Furthermore, the customers' preferences are stochastic, in the sense that the most preferred point moves randomly around the quality circle from one period to the next. The associated preference density is assumed to be uniform around the circumference of the circle; in other words, at the beginning of each period, every point on the circle has a equal chance of being chosen as the most preferred point.

The worker in the firm has imperfect information about customer preferences. Specifically, in the absence of experience gained from selling a product, the worker knows only that the preference density is uniform in each period. In the process of selling, however, the worker is able to gain more preference information. The role of the information gathering process is to partition the preference circle into a number of equal segments and to reveal in what segment of the partition the customers' preferred quality lies. The more time (1-$\tau$) the worker spends selling the product, the more finely he can partition the preference circle, and consequently the better his information becomes. Specifically, letting $M$ be the number of partitions, we assume that

$$M = M(1-\tau), \quad M' > 0 \tag{A5}$$

Letting the circumference of the circle have a length of 4, the length of each partition is 4/$M$, as shown in Figure A.

The decision to produce a particular product means choosing a particular point on the quality circle. The quantity demanded depends inversely on the expected

distance $d$ between the production point and the customers' most preferred point, as indicated in Eq. (A4). Given that the preference distribution is uniform and that the worker knows in which partition the most preferred point lies, the expected distance between the production point and the most preferred point is minimized when the firm chooses the production point that lies at the midpoint of the partition containing the customers' most preferred point. Then the expected distance is[1]

$$\delta = \frac{1}{M} \tag{A6}$$

This is our measure of the worker's information about customers' preferences. By Eq. (A5), the greater the fraction of time (1-$\tau$) the worker spends at the sales task, the more information he gains about customer preferences (i.e. the greater is $M$), the smaller is the distance between the production point and the most preferred point (i.e. the smaller is $\delta$). Thus, the greater the quantity demanded.

Inverting this demand function (A4), $p = p\left(y,(1-\tau)s_\sigma,\delta\right)$ and setting quantity supplied equal to quantity demanded ($q = y$, since the good is nondurable), we obtain the following revenue function:

$$R = p\left[g(\tau s_\pi),(1-\tau)s_\sigma,\delta\right]g(\tau s_\pi) \tag{A7}$$

The information about customers' preferences ($\delta$) is the channel whereby our model captures an informational task complementarity, running from the sales activity to the revenue generated by the production activity.

Substituting (A2), (A3), (A5), and (A6) into the revenue function (A7), we obtain

$$R = p\left[g\left(\tau \cdot s_\pi(\tau)\right),(1-\tau)\cdot s_\sigma(1-\tau),\frac{1}{M(1-\tau)}\right]\cdot g\left(\tau \cdot s_\pi(\tau)\right) \tag{A8}$$

To shed light on the analysis of Section 2, we now express this revenue function in more general terms. For this purpose, we view the returns to specialization and the informational task complementarity as components of the worker's labor endowment (or human capital) at the two tasks. The worker's labor endowment at the sales task is $s_\pi(\tau)$. Since there are assumed to be no informational complementarities

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[1] Since the distance between the midpoint and an endpoint of the partition is 4/(2$M$), the average distance between the customers' most preferred quality and the quality of the produced good is 4/(4$M$) = 1/$M$.

running from production to sales (i.e. information gained at the production task does not increase productivity at the sales task), this endowment consists solely of returns to specialization. By contrast, the worker's labor endowment at the production task depends not only on the returns to specialization $(1-\tau)\cdot s_{\pi}(1-\tau)$ at that task, but also on the informational task complementarity running from sales to production, $1/M(1-\tau)$.

These two sources of the worker's labor endowment – returns to specialization and returns to informational task complementarities – play a central role in our analysis of work organization in Section 2. These sources are relevant to more activities than production and sales. Indeed individuals' performance of most tasks is probably subject to returns to specialization. Many are also associated with both technological task complementarities, and with informational task complementarities in the sense that information acquired by a worker at one task enhances his productivity at other tasks. In this sense, the production and sales tasks in this appendix may be viewed as metaphors that are applicable to many work situations.

Section 2 broadens the model above to make it a convenient vehicle for analyzing the restructuring process in more general terms.

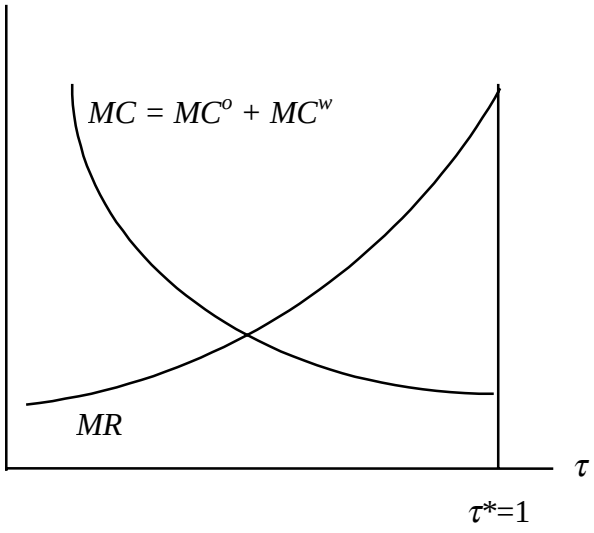


**Fig. 1a:**
**Tayloristic Organization**

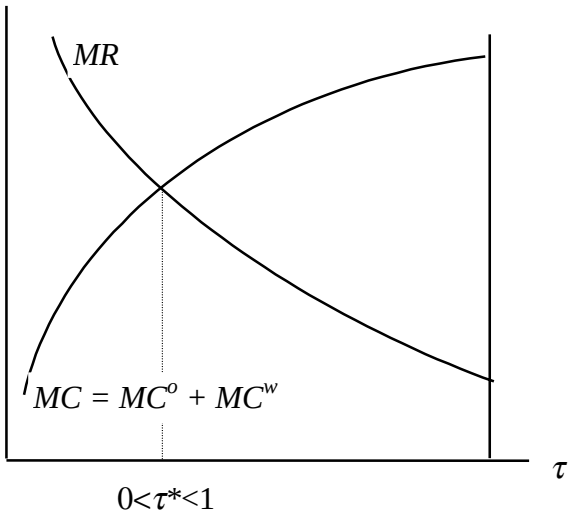


**Fig. 1b:**
**Holistic Organization**

**Figures 1: The Organization of Work**

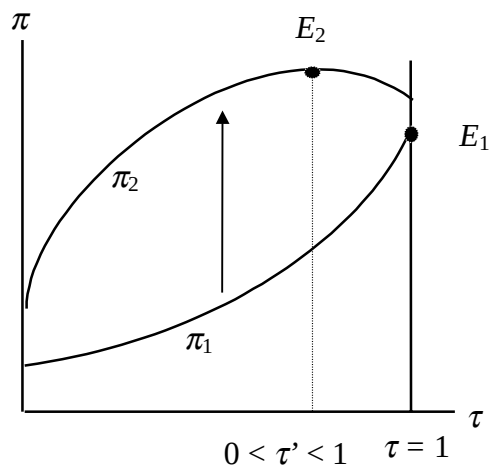


**Fig. 2a:**
**The Discontinuous Process**

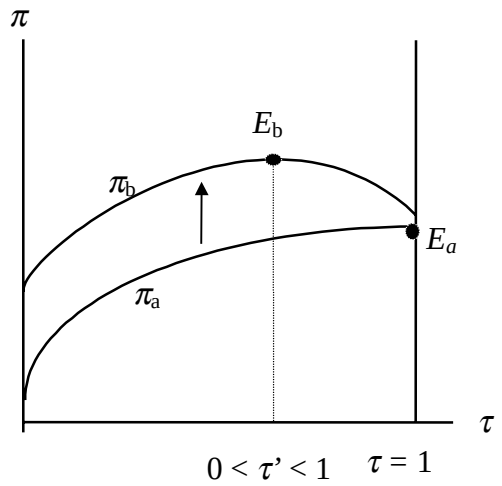


**Fig. 2b:**
**The Continuous Process**

**Figures 2: The Restructuring Process**