THE NEW INDUSTRIAL REVOLUTION

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This article outlines a new framework for understanding the current period of global restructuring, focusing on the relationship between technological change and organizational change. After reviewing the major approaches in the debate over future pathways to industrialization, a new perspective for understanding the 'new industrial revolution' is presented. At the core of this revolution is the emergence of a series of powerful new industrial technologies, which is giving rise to new forces of production and a concomitant transformation in production organization. A new shop floor is emerging, in which innovation and production, intellectual and manual labour are increasingly integrated. As this process of industrial restructuring evolves, success will depend on organizational forms which effectively harness and mobilize collective intelligence.

An employee today is no longer a slave to machinery who is expected to repeat simple mechanical operations like Charlie Chaplin in the film *Modern Times*. He is no longer a beast of burden who works under the carrot-and-stick rule and sells his labor. After all, manual labor can be taken over by a machine or computer. Modern industry has to be brain intensive and so does the employee. Neither machinery nor animals can carry out brain intensive tasks (Akio Morita, Sony Corporation).[1]

The accumulation of knowledge and of skill, of the general productive forces of the social brain, is thus absorbed into capital, and hence appears as an attribute of capital, as opposed to labor, and more specifically of *fixed capital*, in so far as it enters into the production process as a means of production (Karl Marx).[2]

What will the next stage of capitalism be? Will it be industrial or post-industrial, high-tech or low-tech? What do new technologies—semi-conductors, computers, software and biotechnology—mean to advanced industrial economies? How will industry be organized? Which model of industrial organization will emerge as dominant—mass production, computerized automation, flexible specialization, or something new? Which nation or nations will emerge hegemonic? These are the big questions on the minds of those concerned with the future of advanced industrial societies.

In recent years, theorists have put forward a series of alternative models

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of the next stage of capitalism. While the debate has taken different forms in different places, the core issues are strikingly similar. There is a general awareness of and concern for the rise of new technologies as reflected in the outpouring of writing on high-technology industry, post-industrialism, the information economy, and post-Fordism.

But even more than this, there is broad concern for the rise of new organizational forms. Much of this has been stimulated by the decline and transformation of the large bureaucratic Fordist firm as the hallmark of 20th century industry. Much attention and effort has been expended charting the changing organizational morphology of capitalist industry. Many, perhaps most, locate the fundamental change in late 20th century capitalism in this changing social division of labour. Charles Sabel and Michael Piore see the next stage of capitalism in the rise of networks of small flexibly specialized firms.[3] Others like Bennett Harrison see the future in terms of the return and continued dominance of 'big firms'.[4] These and other approaches, including the markets and hierarchies approach of Oliver Williamson, share a common point of departure for they contend that the future of capitalism can best be understood by looking at changes in the organization of the division of labour.[5]

In this article, I outline a new perspective for understanding the 'new industrial revolution'. I emphasize the fundamental role played by technological change, the rise of new forces of production, and concomitant transformations in the organization of production. I focus on the relationship between technological and organizational change, calling attention to crucial *realignments* of the forces and relations of production which open up new sources for value creation and productivity improvement. Such a focus on realignments of the forces and relations of production is in keeping with the nature of industrial progress to the present—the rise of textiles, steel, and automobile production technology as defining features of previous industrial epochs.

I thus argue that what is *new* about the new industrial revolution is to be found in the rise of the new technologies of the microelectronics revolution (eg, semiconductors, computers, software) and the new organizational forms that have emerged to harness them. These new core technologies and/or productive forces are important in their own right in underpinning the rise of whole new industrial sectors, and hence as new sources of productivity, value creation, profit and capital accumulation. They have also set in motion strong 'creative destruction' effects, to borrow from Schumpeter,[6] which underpin the reorganization and revitalization of traditional industries. This is readily apparent in the growing use of computerized maufacturing technologies in the steel, automobile and other industries.

Moreover, at the core of the new industrial revolution lies a sweeping organizational transformation at the point of production. This reorganization I refer to as 'the new shop floor'—by which I mean the blurring of the distinctions between the factory floor and the R&D lab, as innovation becomes more continuous and the factory itself becomes a laboratory-like setting. The new shop floor thus integrates formerly distinct types of work, eg, R&D and factory production, making the production process ever more social. In doing so, the organizational forms of the new shop floor mobilize and harness the collective intelligence of workers as a source of continuous improvement in products and processes, of increased productivity and of value creation.

The new industrial revolution is both technologically and organizationally driven. The new productive forces are characterized by a process which Tessa Morris-Suzuki has termed 'perpetual innovation'.[7] Here, one need only note the incredible pace of progress in semiconductor electronics and computers, where new products and technologies are revolutionized in a period of three or four years. This is a product partly of the wide open technological opportunity for upgrading and improving these technologies and partly of the intense capitalist competition in these sectors. Moreover, the new technologies and productive forces are increasingly digitized and cybernetic—that is they are run by computer programs which encapsulate abstract intelligence. This contrasts with the practical or mechanical mastery of the previous technologies of mass production which both promoted and were based upon deskilling and an attendant separation of intellectual from manual labour, both on the shop floor and between the factory and R&D lab. The new forces of production require an explicit synthesis of intellectual and physical labour. This is occurring through new organizational forms and techniques, eg, the use of work teams and techniques such as *kaizen*, which harness the collective intelligence of workers as a source of continuous improvements in products and processes.

In the new industrial revolution, knowledge itself is increasingly important to production and to the further advance of technology and the productive forces. Knowledge here is seen as a form of human creative capability and value-creating activity. This includes, for example, the knowledge embodied in software programs, which image the labour process and 'run' machines, and the ability of shop-floor workers to modify and improve the production process. This conceptualization of social or collective knowledge thus extends to both the abstract scientific and technical knowledge of R&D workers, which is embodied in innovations and saleable commodities, and the knowledge of shop-floor workers, which provides a crucial source of shop-floor product and process improvements. This conceptualization overcomes the traditional (and to some extent artificial) distinctions between science, technology and factory production, and the related distinction between 'mental' and 'manual' labour. In my view, these are different 'faces' of the same general process of human creativity and value creation.

The organization of work and production and the labour process are also changing to harness the intellectual capabilities of workers. Now, this is not to imply that the extraction of physical or manual labour at the point of production is no longer important, but simply to suggest that intelligence and knowledge are more explicitly integrated into the production process. Simply put, what lies at the bottom of the new industrial revolution is a synthesis of intellectual and manual labour designed to mobilize and harness the knowledge and intellectual capabilities (in addition to the physical labour) of the entire strata of workers, from the R&D lab to the factory floor. Far from romantic or naive, this view explicitly recognizes that the new industrial revolution takes more of the worker, exploiting the worker more completely and totally than before.

This approach provides a more basic and powerful theory for understanding the process of industrial restructuring. It suggests that the many faces and multifaceted experiments occurring in the current round of industrial restructuring—at the level of the organization of firm, corporate structure, industrial relations, supplier and inter-firm relations, and the social division of labour in general—are all ways of grappling with, or adaptive responses to, a more fundamental transformation at the point of production.

In this article I hope at least to clarify some key issues in the current process of global industrial restructuring and, if I am successful, to advance a new way of conceptualizing this process. To summarize my position, I call attention to four salient dimensions of the new industrial revolution:

- the rise of new core technologies and productive forces of micro-electronics;
- the accelerated pace of technological change;
- the rise of a new shop floor encompassing both the factory and R&D lab; and
- the integration of intellectual and manual labour.

Debate over industrial restructuring

Over the past decade or so, there has been an outpouring of theory and speculation over the question of what comes next: what are the new technological, social and organizational forms which might replace industrial mass production? Generally speaking, the debate can be broken down into a series of overarching perspectives.

Long wave perspectives

The first and most basic of these is the renewed interest in the long wave perspectives that grew up almost simultaneously within the Marxian, Schumpeterian and mainstream traditions in the mid-to-late 1970s. The long wave perspective basically contends that capitalism can be divided into a series of stages or historical periods which differ on the basis of underlying technological conditions, organizational forms and so on.[8] This includes the work of Ernst Mandel on the continent,[9] Christopher Freeman[10] and the SPRU school in the UK[11] and the 'social structure of accumulation' perspective in the USA.[12] The SPRU school, most notably Christopher Freeman and Carlotta Perez,[13] emphasize the relationship between technology and social structure, conceptualizing this in terms of 'technoeconomic paradigms'. They suggest that the existing mode of technological–economic organization is in the throes of decline and change because existing institutional and organizational forms are ill-suited to support new technologies. They in turn suggest that advanced industrial societies are entering a new techno-economic paradigm based upon information technologies (ITs). Following Schumpeter, Freeman and Perez place great emphasis on technology efects as they are able to generate adaptive responses in social and economic structures.[14]

Regulation theory

A second approach is that of regulation theory.[15] Going beyond the long wave approach, but still operating within the general context of long swings, the regulation school focuses on relationships between the technological base of production and consumption (or demand), which in their vocabulary constitute an abstract 'regime of accumulation' and the concrete institutional fabric of society, which they refer to as the 'mode of regulation'. This perspective represents a melding of the insights of Schumpeter and Keynes within a basic Marxian perspective which emphasizes the primacy of the forces and relations of production in outlining the parameters of social and economic structure.

There are a number of views from within regulation theory on future pathways of industrialization. Perhaps the most common is that of neo-Fordism.[16] As its name implies, the neo-Fordist position suggests that the current period is not a break with the older model of Fordism, but simply represents an extension and advance of that model. A variant of this is the 'Toyotism' model of Knuth Dohse and his colleagues in Germany.[17] The Toyotism model suggests that Japanese capitalism has established a more efficient way of organizing production, based upon the regrouping of tasks and a fast work pace. Toyotism thus extends but does not break with Fordist principles of mass production.[18]

There are a number of regulation theorists who suggest that a new model of industrial organization is developing as a clear-cut break with Fordism. Roobeek suggests that the rise of new ITs will increasingly disrupt Fordist organization, resulting in the rise of a new post-Fordist order.[19] Although her analysis is somewhat vague, it suggests that microelectronics, biotechnology and new materials technology are bringing about both increased productivity and the 'dematerialization' of production, as for example, fibre optics replace copper wires and genetically engineered products replace traditional chemicals. This in turn requires new social institutions and organizational forms which are different from those of Fordism. The French political economist, Benjamin Coriat, argues that we are witnessing a melding of traditional mass production, automated robotics technologies, and flexibility.[20] Coriat's basic argument is that the rise of automated technologies, eg, numerically controlled machine tools, flexible manufacturing systems and robotics are fundamentally transforming industrial production, leading to a new model of 'flexible mass production'.

Flexible specialization

A third approach is the theory of flexible specialization originally put forward by the Italian economist Becattinni and his students in Italy and later brought to the USA by Michael Piore and Charles Sabel's landmark book, *The Second Industrial Divide*.[21] In that book, Piore and Sabel argue that there is an historical tension between two basic modes of production organization: mass production and craft production. In their politically contingent model of development which they call the 'branching tree model', struggles among political groups (although not necessarily classes) determine which of these forms will predominate in a given historical epoch. Using this general theoretical framework, they contend that the past century or so of industrial history saw the political ascension of mass production organization over craft production. However, the current period of decline of mass production opens up a renewed era of indeterminacy and choice, when a new form of craft production or flexible specialization becomes possible to implement, politically. The ideal-typical model of flexible specialization is the tightly networked firms of Northern Italy which are characterized by high degrees of cooperation and knowledge sharing, joint development and joint involvement in production. They further argue that the seeds of this new form of production are already in place in many of the advanced industrial countries which have and continue to experiment with cooperative networks of small industrial firms.

This and other work has stimulated an outpouring of research on the changing social division of labour in capitalism which integrates a wide range of disciplines and perspectives, including the transaction cost approach to economic organization pioneered by Williamson, the 'social embeddedness' theory of Mark Granovetter,[22] and Charles Sabel's recent arguments regarding the role of trust in economic development.[23] Interestingly, this work has influenced an intense debate over what are the most effective organizational mechanisms for organizing the division of labour, including Bennett Harrison's recent work on 'the big firms'[24] and Charles Perrow's work on networks.[25]

While this work is important, it is situated squarely in the realm of macro-organizational structure, concerned with the division of labour inside and outside the firm, corporate structure, transactional activity and inter-firm relations. This theoretical and empirical preoccupation with the social division of labour and related organizational forms diverts attention from the more fundamental question at hand. To place the matter in perspective: it is akin to elevating the theory of industrial bureaucracy or Alfred Chandler's multidivisional vertically integrated corporation[26] to the level of a theory of 20th century Fordist industrial capitalism. The debate as it is currently taking place revolves around important but none the less second-order phenomena.

The perspective I outline stands in sharp contrast to such conceptualizations of industrial restructuring. I hope to move the debate away from its current preoccupation with the changing social division of labour to the underlying phenomena upon which such macro-organizational changes turn—the rise of new productive forces and attendant changes in the immediate organization of production.

I suggest that fundamental changes in capitalism, when they occur, involve changes at the point of production. Realignments in the forces and relations of production shift the parameters in which value is extracted in production, capital is accumulated, profits are made and economic growth occurs. For example, it was this kind of shift in the nature of production, and not the rise of industrial bureaucracy, that underpinned the shift from simple industrial manufacture to Fordist mass production; in fact the former was largely an adaptive response to the latter. This implies an analytic focus on the production process itself and on the way value is created and harnessed in production.[27]

The new industrial revolution

At the core of the new industrial revolution is the rise of a series of powerful new industrial technologies—semiconductors, computers, computer software and other microelectronic products. These technologies, which first emerged in the late 1940s and 1950s, have gradually come to replace older mechanical technologies as the engines of technological and industrial progress. The nature of their importance is already abundantly clear. Although the microelectronics industry is still relatively young, it is the leading manufacturing employer in the USA, with more than 2.6 million employees—three times as many workers as the automobile industry and nine times more than in steel fabrication.[28]

Moreover, it is these new core technologies which are shaping the transformation or creative destruction of traditional manufacturing industries. Steel mills, automobile assembly plants, machine tool factories, chemical plants and even textile mills are increasingly dependent upon microelectronic and computer technology for industrial automation.[29] In Japan, for example, the use of computers and microelectronics to transform steel making from a batch to a continuous process is referred to as the 'new iron age'.[30] There is even a new technical field referred to as 'mechatronics', which comprises the use of microelectronics to transform older mechanical technologies. Examples of mechatronics technologies include: computerized machine tools, flexible manufacturing cells, and computer-integrated factories.[31]

As the past two decades have shown, the new microelectronics technologies are characteized by an accelerated pace of innovation. In one of the most insightful examinations of the changing nature of contemporary industrial economics, Tessa Morris-Suzuki advances the concept of 'perpetual innovation' to explain the rapid and continuous nature of technological change which follows the shift from older mass production industries to new information-intensive technologies and industries.[32] This can be seen in fields such as personal computers, where state-of-the-art products become antiquated in two or three years; or semiconductors, where cutting-edge technology is outmoded even more quickly, in a year or two. Basically these knowledge-intensive products and innovations are amenable to continuous upgrading and refinement. In this environment, the ability constantly to improve products and processes, to revamp the production process itself, and rapidly to deploy new products and techologies, is critical. And since these process and product innovations are themselves knowledge-intensive, the nature of production is changing from a process based on the extraction of physical labour to a process based on continuous knowledge extraction and innovation, both in the R & D lab and on the shop floor.

Much of the reason for this is related to the nature of new technologies themselves. First, such technologies are characterized by shortened product life cycles and continuous improvement. For example, it has been possible drastically to improve the performance of semiconductors and computers. With recent advances in electronic design automation technology, engineers can use advanced computer workstations to design semiconductors almost instantaneously; these designs can be manufactured using computer-integrated manufacturing technology in less than one week. Using the previous manual design technology, the design process alone would take weeks or months; and the entire process from design through production would typically take years.[33]

In this new environment, the key to economic success lies in the ability to generate new products and new generations of products continuously—to engage in a process of perpetual innovation geared to creating new sources of value continuously. The short product life cycles and rapid performance increases associated with new technologies make innovation itself an increasingly important source of value. Both Schumpeter and Marx recognized that innovation could be the source of tremendous profits, even upheavals of prevailing industries. However, previous technologies tended to be relatively stable. The invention of the light bulb, for example, led to many generations of essentially the same mass-produced product. In the new environment, the accelerated pace of technological innovation results in a more or less continuous stream of commodified products which make old ones obsolete and generate new streams of value, profit and accumulation.

Second, these new technologies are to a large extent digital or cybernetic, and as such stand in sharp contrast to the mechanical technologies of the previous era. Digital technologies increase the relevance of abstract knowledge in production, eg, the ability to develop and use computer programs, to understand rudimentary mathematical and statistical concepts. The ability to use computer-based machines thus requires a certain degree of abstract knowledge and conceptual ability. This is a significant departure from the older mechanical technologies like the moving assembly line which either required practical skill, or more often tended to displace and/or supplement this practical skill by embedding it in a machine.[34]

Third, and quite fundamentally, this is not to imply that there is an automatic or natural relationship between the rise of new technologies or productive forces and the rise of firms, regions or nations to positions of comparative technological and industrial advantage. If that were the case, we would be unable to explain why innovating firms (such as AT&T) and innovating nations (such as the USA) decline. What matters most is how the new productive forces and technologies are harnessed and implemented—what type of *social relations* and *organizational forms* are used to mobilize them and realize their full value. Given this, those organizations, firms, regions or nations which devise the most effective organizational forms to harness the new productive forces will be the most advantaged. They are likely increasingly to gain ground, and indeed overtake the original innovator who has invented but may not be able to implement the new productive forces. This provides an explanation for the decline of the UK *vis-à-vis* the USA at the turn of the century, and the current rise of Japan *vis-à-vis* the USA. In both cases, the innovating nation (and firms which populate it) was unable fully to implement the new technologies and productive forces it had unleashed. It was left to a new set of capitalist organizations, and a new nation, to show the way to a new, more effective mode of organization.

The new shop floor

At the core of the new industrial revolution stands a set of fundamental changes in the organization of work at the point of production. These organizational forms transform the shop floor into a source of constant and continuous improvement in both products and processes, creating a powerful new source of innovation, productivity, value creation and capital accumulation. I refer to this organizational transformation simply as 'the new shop floor'.

The new shop floor includes both the factory and the R&D lab, which together provide the organizational context of the new industrial revolution. The new shop floor involves both the reintegration of intellectual and manual labour and a blurring of the imposed distinctions between innovation and production. There are three related dimensions to this process:

- the harnessing of shop-floor workers' intelligence in production;
- the increasing importance of continuous improvement innovation as a source of value; and
- the blurring of the lines between the R&D lab and the factory.

The crucial first dimension of the new shop floor is summed up in the words of one of its architects, Konosuke Matsushita, founder of the Japanese electronics company that bears his name:

> We are going to win and the industrial west is going to lose out; there's not much you can do about it because the reasons for your failure are within yourselves. Your firms are built on the Taylor model. Even worse, so are your heads. With your bosses doing the thinking while the workers wield the screwdrivers. . . . For you the essence of good management is getting the ideas out of the heads of the bosses and into the hands of labor. We are beyond the Taylor model. Business we know is now so complex and difficult, the survival of firms so hazardous and fraught with danger, that continued existence depends upon the day-to-day mobilization of every ounce of intelligence.[35]

This conception is echoed by Akio Morita, the former Chairman of Sony:

> A company will get nowhere if all the thinking is left to management. Everybody in the company must contribute, and for the lower level employees their contribution must be more than just manual labor. We insist that all of our employees contribute their minds.[36]

Two examples illustrate the power of the new shop floor in practice. The first involves the semiconductor industry. The USA, as is widely acknowledged, both invented and developed the first systems for mass producing semiconductors. The US approach, pioneered by corporations like Fairchild, Motorola, Texas Instruments, National Semiconductor, Intel, and more recent Silicon Valley start-ups such as LSI Logic, Cypress Semiconductor and others, is to develop important new semiconductor breakthroughs in controlled laboratory settings and then to apply the new breakthroughs virtually as is, in manufacturing plants scattered throughout the world.[37] Under this process, the intelligence of scientists and engineers is applied up-front and encapsulated in new technologies. These and other engineers then design the basic manufacturing process, also in a controlled laboratory or small pilot plant setting. After this, the new technology is implemented, virtually unchanged in factory settings. Workers in the factory carry out their production tasks but contribute little if anything to upgrading or improving this new technology or its production process. In formal language, while the process of innovation is *dynamic*, the implementation of technologies and the production process are *static*.

In Japanese corporations, however, the process is strikingly different. While engineers and scientists take the lead in design, factory workers and technicians are constantly consulted on the ability actually to produce this technology.[38] And once the technology is designed and implemented, factory workers make continuous suggestions on how to upgrade and improve both the quality of the technology and the manufacturing process. This leads to continuous improvement in product quality and functionality and continuous improvement in the processes used to make these products. Moreover, it contributes to the rapid development and introduction of new, more advanced product generations. Here, the entire process is *constantly changing and dynamic*.

The second example is from the steel industry, where the combination of new microelectronics technologies and, more importantly, the new shop-floor organization are exerting powerful creative destruction effects. This example concerns the process of cold rolling, whereby thick 'hot-band' steel is turned into thinner steel coils for application in automobiles, office furniture, refrigerators, washing machines and other home appliances. In the USA and most of Europe, cold rolling was traditionally a batch process. Huge rolls of hot-band steel would be carried one step at a time, first to a machine which scraped rust and oxidation from their surface, then to another which bathed them in a chemical solution for further cleaning, to another which dried them off, to still another which pressed them to a desired thickness, and then to final cutting and preparation. Such a process would typically take about one week to complete.

A Japanese steel transplant company in the USA, a Nippon–Inland joint venture I visited in northern Indiana, has turned the cold rolling of steel into a continuous process which takes roughly 10 minutes from start to finish. Nippon Steel achieved this by unleashing the collective intelligence of its workers. The company mobilized both factory workers and R&D workers to combine the various batch processes one at a time. Workers began by combining the entry and scraping processes, and then connected the chemical cleaning and drying process. Next, with the help of computer specialists they added computer controls. Then they connected the two processes together, and so on. This is a highly automated process, controlled by advanced computer technology which the shop-floor workers monitor, modify and program on their own with the full support of management and engineers. The two companies are currently working in the Indiana plant to connect this cold rolling process to another process, called electro-galvanizing, which applies a zinc, nickel or aluminium coating to steel, making it corrosion-resistant for use in automobile body parts. The executives and workers I interviewed at this plant indicated that such innovations were not achieved in an R&D centre; rather, the factory itself had become a laboratory setting for innovation and continuous improvement. In the words of one executive, the factory itself is:

> *a living lab* with bright capable people. The key is to use their brains. Those are your resources, your technicians, your labs, but they're out there on the operating floor. . . . Constant improvement means constant change. You can't get constant improvement if you've got the status quo. How do you get constant change? You get it by doing things you've never done before. Isn't that what they do in a lab—try to figure out things they never did before?[39]

These two examples illustrate the way that the continuous improvements that come from workers' intelligence produce the cumulative product and process innovations that can outdistance and at times replace laboratory breakthroughs. They also highlight the blurring of the lines between R&D and factory production as the factory floor itself becomes a critical arena for innovation.

On the new shop floor, workers' knowledge becomes an explicit element of production—a source of direct value creation and productivity improvement.[40] In this sense, knowledge can be considered a form of human labour which adds direct value in production. Simply put, intellectual and manual labour can be conceptualized as flip sides of the same coin. With the rise of the new industrial revolution, the role of knowledge in production simply becomes more obvious and explicit than it was before.

Moreover, the new shop floor mobilizes group knowledge rather than individual knowledge or skill. Knowledge is in effect socially and/or collectively created. Thus, the capabilities or 'brains' of a variety of different types of workers are integrated and explicitly harnessed in the process of turning knowledge into commodities and new productive forces. This implies overcoming the institutionally imposed divisions separating various strata of workers: R&D scientists who create innovations, engineers who develop them and turn them into commercial products, and shop-floor workers who produce them. Integration of functions is required so that all the relevant actors can interact, exchange thoughts and create new ideas, as a collective entity, and then translate and embody those ideas in new products and production processes. In this sense, the process of innovation and production becomes more explicitly social or intersubjective, a sharp break with the extreme functional specialization of 20th century Fordist mass production.[41]

This also implies some level of (re)integration of mental and manual labour. By this, I do not mean to imply complete or total integration of these two dimensions of human labour, but simply the explicit integration of a significant level of intelligence into the production process. This process is completely bounded by the requirements of capitalism to appropriate value and generate private profit—by the sociopolitical realities of capitalist class relations. In other words, it is not the fact, but simply the form of expropriation and exploitation that has changed. Indeed, increasingly homogenous and interchangeable (though multiskilled) workers, who give up their brains as well as brawn on the new shop floor, may well be exploited more completely and totally than under Fordism.

To mobilize and control knowledge and intellectual labour, the new shop floor requires new forms of property relations. Basically, the system must maximize the creativity of human labour power, while channelling and controlling it as a source of private property and capital accumulation. The mechanism of control is intellectual property rights, which turn knowledge and ideas into private property. Forms of intellectual property include patents and copyrights which are enforced by the state, and trade secrets and contractual agreements between firms or between firms and individuals which allow corporations to own the knowledge and ideas as well as the products produced by the people they employ. Intellectual property rights are an important mechanism of labour control. In the USA, for example, some R&D scientists, engineers and knowledge workers have been able to form their own companies to derive huge profits from their ideas. A number of large companies are trying to use intellectual property rights to prohibit, or at least make it difficult for, their employees to form start-up companies or in some cases even to become direct competitors. In effect, intellectual property rights turn knowledge into property which can be owned, traded and profited from.

Organizational responses on the new shop floor

The new industrial revolution is motivating a variety of organizational responses at the point of production. At the base of the new shop floor is the *self-managing work team*. The team is the concrete organizational mechanism used to harness the collective intelligence of scientists, engineers and factory workers and turn it into commodities—a new microelectronic product, a new computer, a new piece of software or a new form of genetic material. It makes the extraction of intellectual (and manual) labour a quintessentially social, intersubjective and collective process. The self-managing work team devolves a variety of managerial responsibilities to the shop floor. It thus facilitates the *functional integration* of tasks and in turn overcomes the fine-grained, functionally specialized division of labour of Fordist production organization. It is the mechanism for blurring the distinctions between scientists, engineers and factory workers.

For critics, like Mike Parker and Jane Slaughter[42] or Dohse *et al*[43] the team is a vehicle for pumping more work out of workers and for achieving higher levels of stress—thus their term, 'management-by-stress'. This however captures only part of what teams do. The team is the mechanism through which workers are used to solve production problems and innovate. It becomes the source for adapting to production bottlenecks as workers use their own intelligence and knowledge to devise cooperative strategies to overcome such bottlenecks. The team is a simultaneous source of motivation, discipline and social control for team members, driving them to work harder and more collectively. In this way, workers are encouraged, stimulated and provided with incentives to generate new ideas and continuously improve the production process. Perhaps most importantly, teams tap the collective knowledge of a group. Teams comprise the micro-organizational solution to the problem of extracting both knowledge and physical labour from workers. This is an inherently social way of creating value and achieving productivity improvements. Workers are thus made to mobilize their own intellectual labour 'voluntarily'.

Different firms and different nations are responding in different ways to the new industrial revolution. This is to be expected. Here it should be remembered that these various adaptive responses are neither automatic nor governed by a process of natural selection; rather these relationships are politically mediated—imposed and negotiated by social groups and classes. As both Schumpeter[44] and Marx[45] pointed out, such adaptive responses bear the imprint of past history, and are strongly influenced by existing social structures, organizational forms, management practices, forms of labour organization, political constellations, articulations of class struggle and so on. In the terms of Richard Nelson and Sidney Winter the past 'selection environment' effects and shapes new paths of change;[46] or in the framework of Mancur Olson, institutional rigidities create blockages to industrial progress.[47] Furthermore, many theorists have noted that different forms of production organization (eg, craft production, simple industrial production, Fordist mass production, etc) frequently coexist within a given political–economic formation and that it is impossible completely to generalize from one form to the orgainzation of all economic activity. Indeed, it is frequently the case that different forms and articulations of production organization exist in a symbiotic, mutually dependent way to constitute a political–economic totality.

Japenese corporations are perhaps the best exemplars of the new shop floor, though similar arrangements can be found in a number of 'progressive' corporations in the USA—eg, 3M, Hewlett Packard and Xerox—Europe—eg, Pirelli—and Scandanavia—eg, Volvo. In these firms, teams of between five and 15 workers are responsible for the organization and distribution of work to team members, basic quality control, and correcting problems that crop up on the line. In Japanese corporations, teams of shop-floor workers mobilize collective knowledge for continuous improvement through a process referred to as *kaizen*. Workers are evaluated and receive financial rewards for contributing their suggestions and ideas—for actually making small improvements in products and processes. Further, the physical layout of assembly lines helps this process. Modular lines may be used in place of the long dedicated transfer lines of Fordism. These arrangements include the use of more general purpose machines which can be used for a variety of different production processes. These arrangements facilitate rapid shifts between different products within a product family. Under this kind of set-up, lines can be easily converted to different products and workers can perform a number of tasks on different machines simultaneously.

Moreover, teams are the basic mechanism for moving decision making down to the shop floor and for tapping the intelligence of factory workers. In recent studies, Haruo Shimada advances the concept of 'humanware' to describe Japan's smart production workers;[48] Masahiko Aoki[49] and Kazuo Koike[50] use the idea of 'learning by doing' to convey the combination of intelligence and production. Other factors contribute to functional integration on the shop floor. Under the concept of 'management by walking around', engineers spend a great deal of time on the factory floor, talking to shop-floor workers and devising on-the-spot solutions to problems.

The new shop floor integrates and harnesses knowledge along all stages of the innovation–production spectrum, especially the R&D lab which becomes ever more crucial. Japanese firms, and some in the USA and Europe, have pioneered new modes of functional integration to blur the boundaries between the R&D lab and the factory. Under this approach, teams are used to develop links to and connections across the innovation–production spectrum. Overlapping membership allows R&D workers to work along product development engineers and even factory workers, blurring the boundaries among them. This creates an interplay and synthesis of various types of knowledge in an explicitly social context.

This model of *functional integration* is a radical departure from the

Fordist assembly-line model of innovation which was distinguished by a functionally specialized division of labour within various R&D activities, between R&D and manufacturing, and among firms and their suppliers. In Fordist firms, this entire spectrum was split into self-contained and isolated segments. It thus became difficult and at times virtually impossible to translate knowledge embodied in human labour power into commercial innovations or to translate innovations into mass-produced commodities. Hence the adaptation of a fully functionally integrated model is likely to be difficult in organizations or national systems with a strong Fordist legacy.

This process of functional integration can extend beyond the boundaries of the traditional firm into broader corporate galaxies. The hub-spoke supplier systems of large corporations are a way to tap and reproduce the collective knowledge of workers in a complex of firms. Knowledge is mobilized in such a system by a combination of cooperation and coercion. Ronald Dore's concept of 'relational subcontracting' captures one side of these relationships.[51] Often, however, large hub companies apply pressure and coerce their suppliers to innovate, cut prices and 'share' proprietary data, information and technology with one another for the 'benefit' of the whole complex, ie, the hub or parent firm.[52] Essentially, the large firm orchestrates an intense cross-flow of information within its supplier complex. In doing so, it harnesses the knowledge and intelligence that is spread throughout the system of suppliers. The parent or hub firm is also able to launch new products and product lines through 'sponsored spinoffs'. Under this system, R&D scientists work on projects and gestate them until the point that they develop into actual products and product lines. As they grow, they can be spun-off into self-standing enterprises in their parent's supplier galaxy, and allowed to grow into self-standing businesses.

Some firms and organizations, including many in the USA and Europe, have organized workers in teams, but have not given any increased authority in or responsibility for decision making. These firms have been unable to unseat the long legacy and well entrenched interests that have grown up around Fordist organizational forms. Moreover, once knowledge and skill have been removed from workers, it may be difficult to reimpose them. Here, what has occurred is little more than a regrouping of work along the lines of a 'group Fordism'. Such a change in surface-level organization without substantive change in decision-making authority is unable to achieve the integration of intelligence and knowledge that is required to harness the full potential of the new productive forces. Here, surface relationships are crystallized within an essentially unreconstructed Fordist shell. This kind of system is proving ineffective, as it is unable to turn knowledge into innovations and innovations into mass-produced commodities.

Finally, in the high-technology outposts of Silicon Valley and Route 128 what we find is a partial and truncated version of the new shop floor. Here, both the organization of work and patterns of remuneration are organized to pump maximum work out of highly skilled R&D workers. Thus, the labour process for R&D workers is one which is designed to harness their collective knowledge and turn this quickly into commodities or innovations. However, this model of work organization does not extend to shop-floor workers who are organized for the most part in pre-Fordist sweatshop conditions in the USA itself and increasingly in the Third World.[53] This adaptive response is thus unable to mobilize the continuous improvements on the new factory floor which are needed to achieve incremental product and process innovations and harness the full capabilities of the new productive forces.

Also, the high-technology industrial networks of Silicon Valley and Route 128 attempt to mobilize knowledge at the extra-firm level. Such inter-firm networks benefit from huge agglomerations of knowledge workers and a network supportive of such workers who form into various combinations as new start-up firms.[54] The basic mechanism for creating and generating knowledge is the labour market and the process of new firm formation. But there are limits to this kind of knowledge sharing and cross-fertilization, as evident in the strong trend towards proprietary knowledge and the wave of law suits over knowledge embodied in ideas, products and human labour power in Silicon Valley.[55] Here, strong capitalist competition limits knowledge sharing. While some degree of informal knowledge sharing between scientists does occur, it is limited by the nature of competitive relations and the threat of law suits. Furthermore, the external labour market is characterized by an extreme 'hyper-mobility' of labour,[56] as R&D scientists and engineers move from company to company causing serious disruptions in R&D projects and a more general externalization of innovation among companies.

Conclusions

In this article, I have attempted to outline a new framework for understanding the current period of global industrial restructuring steeped in a fuller and richer understanding of the relationship between the new forces of production and the forms of organization in which they are enmeshed. I have argued forcefully against approaches which place primary emphasis on the organization of the social division of labour. Major technological advances are once again motivating, and in turn being shaped by, a significant revolution in production organization. A new shop floor is emerging alongside the new productive forces, one where innovation and production, intellectual and manual labour are increasingly integrated. It is this fundamental realignment of the forces and relations of production which is motivating and selecting from among the various models of industrial restructuring that have emerged and continue to emerge around the globe.

The world of the new industrial revolution is not abstract, implausible and indeterminate as its theorists would have us believe. It is concrete and predictable. There is little reason to expect a prolonged flourishing of alternative models as some have suggested. Such a flourising will only occur if two or more models are more or less equal, or if they are protected from competing with one another. In my view, the current period is more appropriately thought of as a transitory one—of adaptation, organizational experimentation, and general sorting out from which a dominant model is emerging. The critical benchmarks from which we can better understand the present and predict the future are already within our view. In the new industrial revolution, we can expect those organizational forms which effectively harness and mobilize collective intelligence to outperform those which do not and eventually to diffuse throughout the world economy.

I conclude by simply stating that the theoretical constructs outlined here represent the product of an evolving understanding. These ideas and concepts constitute the beginnings of a general theory of a new stage of capitalism derived from empirical research and observation. Although this article is the product of some five years of field research in factories and laboratories, it remains a conceptual first pass. There are areas where more empirical research needs to be done. For example, we need to know more about the sweeping revision of intellectual property rights and the attendant commodification of knowledge and ideas. And we require deeper understanding of the basic and fundamental contradiction which lies at the bottom of the new order—the unparalleled unleashing of human creative capabilities and the need to channel those capabilities within the bounds of capitalist social relations, as this is likely to have serious implications for future economic and social development. And as with all theory, this one must now be subject to vigorous testing, evaluation and revision.

In the end, I can only hope to have added clarity to an admittedly fuzzy picture and perhaps to cut through some of the interference projected by prevailing approaches. Only a much larger, collective project can bring that picture into fuller and more complete resolution.

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40. The roots of this conceptualization can be found in Marx, who saw knowledge as essentially a form of human creative activity or 'labour' broadly construed. Writing in the *Grundrisse, op cit,* reference 2, page 706, Marx suggested that:

'Nature builds no machines, no locomotives, railways, electric telegraphs, self-acting mule, etc. These are the products of human industry . . . They are *organs of the human brain, created by the human hand*; the power of knowledge, objectified. The development of fixed capital (eg, machines) indicates to what degree general social knowledge has become a *direct force of production*' (emphasis in original).

41. Under Fordism, the organization of production was premised upon a basic separation of mental and manual labour. According to Harry Braverman (*Labor and Monopoly Capital* (New York, Monthly Review Press, 1974), management tried to take power away from workers by 'deskilling' them. The basic idea was to separate the conception of tasks from their execution. And, as Schumpeter (*op cit*, reference 6) noted, under Fordism, innovation —the process of turning rough technological ideas into commodities—was placed in specialized R&D labs. In the Fordist division of labour, then, intellectual tasks became formally the responsibility of scientists and engineers who worked in R&D labs, while manual labour took place in factories (Florida and Kenney, *op cit*, reference 31). However, this separation of mental and manual did not necessarily result in the most efficient production organization. This could be most clearly seen when workers would 'work to rule'—stop applying their intelligence in production—bringing the production process to a halt. Indeed, the separation of mental and manual labour under Fordism did not come about because shop-floor workers were unable to unify their manual and mental labour; rather, the organization of production and its class relationships imposed this separation. As Herbert Marcuse recognized fairly early on ('Some social implications of modern technology', in Andrew Arato and Paul Piccone (editors), *The Essential Frankfurt School Reader* (New York, Urizen Books, 1978 (original 1941)), pages 138–162), the 'gap' between engineers and factory workers was 'maintained more by the division of power than by the division of work' (page 153).
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