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AUTHOR Norman, Colin
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ABSTRACT

A combination of revitalized employment policies, greater industrial democracy, and new ways of restructuring both the hours of work and the fruits of technological change are essential if the benefits of the microelectronics revolution are to be equitably shared. Microelectronic technology promises an era of benefits and the electronic age is already well under way. As it progresses during the last two decades of the twentieth century, it will lead to improvements in productivity in factories and offices, changes in the way information is processed, stored, and communicated, and alterations in the content of many jobs. Differing rates of development of the electronics industry may lead to shifting advantages of competition in the international marketplace. Like all major technological changes, the transition to microelectronics will raise difficult political issues, among which the impact on jobs and employment is the most prominent. (MEF)

Microelectronics at Work: Productivity and Jobs in the World Economy

Colin Norman

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It is [illegible] to sit up and take notice when a committee of the National Academy of Sciences states that "the modern era of electronics has ushered in a second industrial revolution . . . its impact on society could be even greater than that of the original industrial revolution." Academy committees are not usually noted for hyperbole.[1]

The Academy is not alone in suggesting that recent advances in microelectronic technology are harbingers of sweeping social changes. In the past decade, when most industries experienced sluggish growth and [illegible] innovation, the electronics industry saw its sales boom and its products change dramatically. The key to these developments is the ability to imprint tens of thousands of electronic components and complex circuits on chips of silicon one-fourth the size of a postage stamp. This technological feat has shrunk the size of electronic equipment, increased the power and flexibility of small computers, and slashed the cost of storing and manipulating information.

The new microelectronic technology has brought within reach a vast array of products and processes that would have been unattainable a few years ago. Computer-controlled machines are already being introduced into assembly lines, newspaper composing rooms, banks, supermarkets, and offices of every kind; electronic controls are being incorporated into automobile engines to regulate combustion and exhaust emissions; a multibillion-dollar industry manufacturing computer games, digital watches, home appliances, and

[illegible] wish to thank Ann Thrupp for her assistance with the research for this [illegible].

6 other novel electronic consumer goods has sprung up almost overnight.

Some of the technological developments that lie at the core of this electronic revolution are less than a decade old. An attempt ... their social and economic significance is thus akin to forecasting the impact of the automobile on society as the first Model T rolled off the assembly line. Yet one thing is clear: microelectronic technology will have a pervasive and long-lasting influence on international trade, patterns of employment, communications, industrial productivity, entertainment, and social relationships.

The manufacture alone of electronic goods will have an important economic impact in the coming years. According to several estimates, the electronic industry will rival the automobile, oil, steel, and chemical industries in sales by the end of the eighties. Indeed, one observer has suggested that "if steel and oil have been two of the key ingredients of modern, industrial society up to now, many believe that in the remainder of this century it will be the state of a nation's electronics industry that signifies whether it is a developed nation or not."[2]

Yet it is the flexibility and ubiquitous applications of microelectronic devices rather than their manufacture that will make them an extremely potent force in social and economic life in the decades ahead. They offer several attractive possibilities. Electronic control of industrial and office machinery could result in increased productivity, the elimination of dangerous jobs, and the automation of boring, stultifying work. When used to control engines and industrial processes, microelectronics offers potential savings of energy and other resources, and the replacement of mechanical components with electronic equipment can increase the flexibility and improve the reliability of many goods and services.

But the spread of microelectronic technology will be a mixed blessing. Its impact on levels and patterns of employment could be enor-

> **"Electronic control of industrial and office machinery could result in increased productivity, the elimination of dangerous jobs, and the automation of boring work."**

mous. The labor-saving potential of microelectronics is such that many jobs could disappear as employers take advantage of the increased productivity offered by computer-controlled equipment. Indeed, it is this potential that provides much of the driving force behind the rapid adoption of the technology. Concern about the employment implications of microelectronics is heightened by the fact that the technology is coming to fruition at a time when the prospects for overall economic growth—and hence job creation—seem particularly grim.

The complex social and economic issues raised by the development of microelectronics are likely to pose difficult problems for industrial and economic policy in every country. An intense debate has already erupted in Europe over some of these issues, though it has yet to be joined in the United States. Moreover, the special problems posed for developing countries by the emergence of a technology that could fundamentally affect patterns of production, world trade, and international investment have received only scant attention.

The Micro Revolution

In 1946, the world's first electronic computer was switched on at the Moore School of Engineering in Pennsylvania. It was an impressive machine. Called ENIAC (Electronic Numerical Integrator And Calculator), it occupied a large room, contained 18,000 vacuum tubes, and consumed enough power to drive a locomotive. Today, a computer with equivalent capabilities fits into a pocket, costs less than $100, and runs on flashlight batteries. Such are the dimensions of the microelectronic revolution.

As electronic components have shrunk both in size and cost, they have become pervasive. "It is not an exaggeration to say that most of the technological achievements of the past decade have depended on microelectronics," asserts Robert Noyce, a leading figure in the industry. He points out that microelectronic devices have played a central role in the development of space technologies, missiles, calculators, digital watches, word processors, and industrial control equipment; yet he suggests that we have seen only the tip of the iceberg. "The microelectronics revolution," says Noyce, "is far from having run its course."[3]

The effects of the microelectronic revolution will be markedly different from those of the Industrial Revolution, however. The development of industrial technology largely enhanced human physical capabilities, enabling people to harness more energy, process and shape materials more easily, travel faster, and so on. But the development of microelectronics extends mental capabilities, for it increases the ability to process, store, and communicate information, and it enables electronic "intelligence" to be incorporated into a broad range of products and processes.

It has taken just 30 years for the microelectronic revolution to develop, and only in the last five years has it begun to take off. It started in 1947—the year after ENIAC made its debut—with the development of the transistor. The basic building block of all modern electronics, the transistor swiftly rendered obsolete much of the circuitry on which electronic equipment had been based. Transistors consist of semiconductor material—usually silicon—to which minute quantities of impurities such as phosphorus or boron have been added in discrete regions. The impurities alter the electrical properties of the semiconductor, causing it to conduct electricity when it is subjected to sufficiently large voltages. Transistors usually function like tiny electronic switches, shuttling electrons around electrical circuits.[4]

Since transistors are smaller and much less power-hungry than the vacuum tubes they replaced, goods such as radios, television sets, and computers became more compact during the fifties and they required relatively little power to operate. For better or worse, the transistor radio emerged. But there was a limit to this trend: individual transis-

"In three decades, a roomful of vacuum tubes, wires, and other components has been reduced to the size of a cornflake."

tors, like the bulky components they replaced, still had to be wired together, and thus a piece of equipment with many thousands of electrical parts remained a pretty hefty contraption. This posed serious constraints for military and space hardware, where size and weight are particularly critical; consequently, the U.S. Government and private companies began to pour money into further miniaturization efforts.

These investments paid off in 1959 with the development of the integrated circuit, the centerpiece of microelectronic technology. In the late fifties, transistors were produced in batches in thin slices of silicon that were later cut into sections, each of which contained a single transistor. Scientists at Texas Instruments and at Fairchild Camera and Instrument Company had the bright idea of wiring the transistors together into a complete circuit while they were still in the slice of silicon. The result was the first integrated circuit. The first experimental devices were made by connecting the transistors together with wires, but later models had tiny aluminum conductors deposited directly on the semiconductor surface.

As the design and construction of integrated circuits improved, the number of transistors and other electronic components, such as resistors and diodes, that could be placed on a single piece of silicon increased exponentially, doubling roughly every year from the early sixties to the late seventies. By 1980, the most densely packed circuits contained close to 100,000 components on a silicon chip measuring just five millimeters across, and the aluminum conductors linking them together were about 30 times thinner than a human hair. In three decades, a roomful of vacuum tubes, wires, and other components has been reduced to the size of a cornflake. And the process is not over yet. Although it becomes increasingly difficult to design and imprint the circuits as the density of the components increases, chip manufacturers are confident that by 1990 they will be able to produce integrated circuits containing at least one million components. Already, chips containing some 250,000 components are being designed.

Putting thousands of components on a silicon chip is, to put it mildly, a difficult process. First, the layout of the components and the pattern of connections between them are designed with the help of a computer. The circuit design is then drawn by the computer on a series of photographic plates, which are used to print a reduced image of the design on glass plates, called masks. These masks form the heart of the process of imprinting the circuit design on silicon chips; like photographic negatives, they can be used time and again to produce multiple copies of a particular integrated circuit.

Imprinting the transistors and other components requires microscopic areas of the silicon chip to be "doped" with impurities, and a maze of connections more complex than the street plan of a large city to be laid down between them. It is done in an automated process in which thousands of identical circuits are constructed simultaneously. The basis of the process is a complicated photoengraving technique that uses the masks to determine the pattern in which the impurities are embedded and to establish the maze of aluminum connections.

This intricate piece of technological wizardry has slashed the cost of electronic circuitry. The price of a given amount of computer memory, for example, dropped by a factor of about 50 during the seventies—at a time when the price of just about everything else rose by leaps and bounds. And equally sharp reductions in the price of the electronic "brains" of consumer goods such as calculators and electronic watches have transformed them from luxury products to everyday items.

The chief reason for these plummeting costs is that once the integrated circuits have been designed and etched onto the masks, they can be mass-produced. As with automobiles and other assembly-line products, the immense capital costs of setting up a manufacturing plant are spread over a large number of items. Moreover, the actual production process costs about the same no matter how many components are packed on each chip. This means that as more and more transistors are crammed into each circuit, the cost of each transistor drops. In 1960, an individual transistor cost about $10; today, a transistor in an integrated circuit costs a fraction of 1¢.

This combination of shrinking dimensions and declining costs would alone be sufficient to ensure an expanding market for integrated circuits. But the circuits have yet another valuable attribute: they perform their electronic operations extremely rapidly. As more and more components are packed on a chip, the distance between them shrinks and the time it takes for electrons to shuttle from one component to another is reduced. Thus, in general, the more densely packed an integrated circuit is, the faster it functions. This is especially important in the performance of computers, which carry out millions of electronic operations in the processing and manipulation of data.

Most integrated circuits are designed for specific tasks, such as operating a digital watch or storing information in a computer memory in the form of pulses of electrons. In 1971, however, the American microelectronics company Intel brought out a radically different, more flexible type of integrated circuit that vastly extended the range of applications of microelectronic technology. Intel essentially put the entire central processing unit of a computer—the complex circuitry that processes information and carries out instructions—on a silicon chip. The resulting integrated circuit, called a microprocessor, can be programmed like a computer to carry out a broad range of functions.

A microprocessor is essentially a device for processing information that is fed to it through a keyboard, a wire from an instrument, or some other input mechanism. Once the information is converted to an electronic binary language (with only two possible words, zero and one, which are determined by whether the transistors are switched "on" or "off"), it is processed according to instructions stored in the microprocessor's own memory or in other, attached memory circuits. These instructions, called programs, cause the microprocessor to perform a series of logical steps in which pulses of electrons are moved through its circuits, stored, and moved again at extremely high speeds—a process a little like the high-speed shuffling of beads on an abacus. When these steps are completed, the microprocessor activates an electrical circuit that is connected to an output device, such as a screen that displays the results of a calculation or a switch that opens or closes a valve.

Even the early microprocessors boasted more computing power than ENIAC, and their capabilities have since increased many times over. The central processing units of powerful computers that would have cost thousands of dollars a few years ago are thus being mass-produced for a few dollars apiece. A startling achievement in its own right, this development means that the computer's ability to process information and carry out instructions can now be incorporated relatively cheaply into a variety of machines, ranging from cruise missiles to microwave ovens.

These tiny electronic devices did not spring suddenly from the laboratory bench and begin to change society, however. As with any new technology, the development of microelectronics has been pulled along by economic and political forces. During the sixties, the U.S. military and space programs provided the driving force, accounting for most of the integrated circuits produced in the United States. This burgeoning military demand provided a stable market for the small, innovative microelectronics companies that spearheaded the technological development, and it helped launch the industry on its high-growth trajectory.[5] It also changed the nature of many weapons. Microelectronic controls now constitute the brains of guided missiles, "smart" bombs, electronic sensors, and other ingredients of modern warfare, and they have played a central role in the development of military space systems.

During the seventies, the focus shifted toward civilian applications, and commercial incentives are now pushing the development of the technology. The manufacture of integrated circuits has turned into a $10-billion-a-year industry, and sales are growing at the

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phenomenal rate of 30 percent per year. Military programs account for about $1 billion worth of microelectronic devices, and the rest of the expenditure is widely disseminated throughout the economy.[6]

The economic impact of microelectronic devices is far greater than their sales figures suggest, however. "I like to think of semiconductor technology and its evolution as being the crude oil of the electronics industry," says Jerry Sanders, president of the U.S. semiconductor company Advanced Micro Devices. Electronics, he notes, is "a $100 billion industry now, and headed for perhaps $800 billion by the late 1980's—all grounded on semiconductor components."[7]

The electronics industry thus faces a period of growth that will propel it into the front ranks of the world's major industries. The microelectronic revolution, by broadening the applications of electronic devices and slashing their costs, has sown the seeds of this expansion. And as microelectronic devices have become more pervasive, the nature of many products is changing rapidly.

One conspicuous result of this flood of microelectronic technology is a growing array of new consumer goods. In the space of just a decade, the manufacture of pocket calculators, digital watches, electronic games, and children's toys has mushroomed into a $4-billion-a-year business. And new electronic gadgets, such as language translators and calculators built into wristwatches, are entering the market in quick succession.[8]

Established products are also being transformed as microprocessors and other integrated circuits replace mechanical and electromechanical components. Some washing machines, for example, are now equipped with a microprocessor that controls the sequence of wash cycles and water temperatures according to instructions entered through a calculator-style keyboard; about 60 percent of the microwave ovens currently sold in the United States are equipped with similar microelectronic timing devices.[9] More sophisticated controls are being incorporated into a range of machine tools, guiding the actions of cutters, welders, drills, and stamping machines.

There are several advantages to incorporating microprocessors into household as well as industrial products. Microelectronic controls are more reliable and flexible than their mechanical counterparts. They can be used to regulate complex cycles lasting from a few seconds to several hours, and they can quickly be reprogrammed to enable the machines they control to perform different tasks. The reduction in the number of moving parts that results from the replacement of mechanical components with electronic controls can, moreover, be significant: a sewing machine marketed in the United States in the late seventies uses a single integrated circuit to control the sequence and pattern of stitches, in place of some 350 cams, gears, and other parts.[10]

The automobile industry is also turning to microelectronics in its headlong rush to improve fuel economy and reduce exhaust emissions. In the next few years, virtually every new car made in the United States will have a microprocessor under the hood to control fuel intake or ignition timing. This application alone will account for millions of integrated circuits each year.

The biggest single user of microelectronic devices will, however, be the computer industry itself. The development of cheap and powerful microprocessors and integrated memory circuits has spawned a broad range of small, flexible computers that can be programmed for a variety of tasks. Just a few years ago, the cheapest computers on the market cost hundreds of thousands of dollars and they were big, powerful machines. Now home computers the size of a typewriter can be bought for less than $1,000, and powerful business machines for less than $10,000. These developments have brought computing power to the fingertips of a rapidly growing number of people, and they have opened the way for an expansion of electronic record keeping, information processing, and data gathering. They have also blurred the distinction between computers and other office machinery, for computer intelligence can now be built into typewriters, copiers, and a host of other pieces of office equipment.

Finally, one of the most important but least conspicuous uses of microelectronics in the coming years will be in the improvement of telecommunications systems. The last great change in telecommunications networks took place only a few decades ago, when manual telephone exchanges were replaced by electromechanical switching stations. But those systems are already out of date, and they are now being replaced by faster, more reliable all-electronic exchanges and satellite linkages, both of which rely heavily on microelectronics.

Most industrial countries are now embarking on the enormously expensive task of upgrading their telecommunications systems. As a result, telephone networks not only will be able to handle more calls, but they will also be better equipped to relay electronic messages between computers, word processors, and other intelligent machines. In other words, the improved telecommunications systems will provide a vital link that will permit growing numbers of computerized machines to "talk" to each other. This pending merger between telecommunications, computing, and information processing is likely to be the most far-reaching consequence of the microelectronic revolution, for it will greatly extend humanity's capacity to process and transmit information.

Developments in microelectronics have thus resulted in startling changes in the dimensions, cost, performance, and reliability of electronic components. As the technology is pushed even further, with hundreds of thousands of components jammed on a silicon chip, the power of microelectronic devices and their range of applications will be enhanced even more.

The Automated Factory

The popular science fiction image of the factory of the future pictures an immense computer directing the operation of scores of machines that turn out parts to be assembled by humanoid robots. The reality will not quite match up to this vision, however. Instead of one giant computer, several minicomputers and microprocessors will do most of the machine-minding, and the robots on the assembly line will look nothing like humans. And far from being relegated to the distant realm of science fiction, some elements of the factory of the future are already being installed in the industrial plants of today.

The speed with which the fully automated factory advances will depend on a host of economic and social obstacles, and its progress across the industrial landscape will be highly uneven. Nevertheless, it is clear that the microelectronic revolution of the seventies will fundamentally affect production and productivity in some industries during the eighties and beyond.

One area in which computers are likely to play a leading role is in the operation of giant industrial plants such as oil refineries, power stations, chemical factories, pulp and paper mills, and steelworks. In these huge enterprises, raw materials are treated in a continuous process that is critically dependent on the maintenance of correct temperatures, pressures, and rates of flow. These must all be monitored and controlled at key points in the plant, where valves are manipulated to keep the process running smoothly. Although computers have long been used to perform some of these tasks, their numbers have been limited by high costs and by the difficulties involved in programming a central computer to carry out a complex range of operations. These problems are, however, greatly reduced with microelectronics.

Microprocessors are now being incorporated into measuring instruments, which enables them to control parts of a production process directly, and to convert measurements of pressure, temperature, and other variables into an electronic language that can be fed into a central computer. This enables computer power to be distributed throughout a plant to control individual parts of the production process under the general guidance of the central computer. This combination of sophisticated measuring devices and distributed computer control greatly reduces the problems involved in programming a single powerful computer to control all the factory operations.[11]

Although the technology has progressed to the point where such automation is possible, the nature of continuous-process industries will not be changed overnight. As a study by the European Trade Union Institute succinctly points out, "an expensive steel or chemicals plant will not be scrapped simply to allow the introduction of a computerized control system forming perhaps only 10 percent of the total plant cost."[12] Nevertheless, new plants built during the eighties and nineties will have many more computers and far fewer people than factories in operation today. Moreover, the flexibility of the new control systems will allow individual parts of existing plants to be computerized on a piecemeal basis.

The application of microelectronic controls in large continuous-process plants will extend the use of computers in an industrial sector that is already highly automated. In many other factories, however, microelectronic devices will enable computers to be used for tasks that have previously remained relatively immune to automation. Indeed, it is in the machine shops and on the assembly lines of manufacturing industries that microelectronics will ultimately have its chief industrial impact.

The key to the burgeoning use of electronics on the factory floor lies in the declining costs and the increasing power and flexibility of small computers and microprocessors. Computer intelligence can now be distributed throughout manufacturing operations, either by using computers to control parts of a production process or by building microprocessor controls directly into machine tools. Computer-controlled machine tools are nothing new. Ever since the early fifties, some heavy machines such as lathes, grinders, and cutting machines have been made to operate in a pattern set by coded instructions developed by a computer and fed into the machine through punched paper or magnetic tape. These so-called numerically controlled machine tools have gradually become more intelligent as they have been linked directly to powerful minicomputers and microprocessors. Simply by changing the instructions to the computer or microprocessor, these machines can be swiftly reprogrammed to shift from one task to another.[13]

This flexibility is of fundamental importance. Until now, automation has been largely restricted to factories that turn out thousands of identical products, because it has been too costly to retool machines at frequent intervals to perform new tasks. But the development of reprogrammable machinery makes it economically feasible to automate production processes that involve short production runs and frequent changes in machine settings. The majority of manufacturing processes fall into this category.

Computer-based automation is being extended to the assembly stage of production, for a new generation of microelectronically controlled robots is now being developed to perform a wide range of complex tasks on assembly lines. These machines bear little resemblance to the androids of the film *Star Wars*. They consist of a flexible arm, with two or more joints that are controlled automatically, on the end of which is a tool such as a drill or a paint spray. Some of the more advanced robots can be reprogrammed by typing new instructions on a keyboard or by inserting a new magnetic disk into the machine. A computer-controlled welding machine, for example, can weld a Ford Pinto one minute, and a Mustang the next. So far, the use of robots is relatively limited, because even the brightest members of the current generation of machines are not too intelligent. A robot on an assembly line, for instance, must have identical parts fed to it at a constant rate and in an unvarying alignment because it lacks any sense of sight or touch.

Consequently, most of today's working robots are engaged in repetitive tasks such as welding and paint spraying that frequently involve hazards when they are performed by humans. Fiat has already installed a computerized welding system in two of its Italian plants.

"Japan leads the world
in the number of robots installed, and
the global population of robots
is expanding fast."

Operated by just 25 people, these systems can turn out 1,200 car bodies per day. "Designed by a computer. Silenced by a laser. Built by a robot." proclaims an advertisement in Europe for the Fiat Strada. In Britain, computerized welding machines being installed in BL Ltd.'s Longbridge plant will be able to weld a complete car body in 42 seconds, allowing the factory to produce an extra 342,000 cars per year with 70 percent fewer workers. And in Nissan's Zama plant near Tokyo, 96 percent of the welding is done by robots.[14]

The automobile industry in the United States is also moving rapidly to install robots in its factories. It has a golden opportunity to automate its plants, for it is in the midst of a $70-billion retooling program aimed at the production of a generation of smaller, more efficient cars. According to one estimate, about 500 robots are already clanking away in American automobile manufacturing plants, and the number is likely to double within the next few years.[15]

It is not just in car production that robots are making major inroads. General Electric, for example, is planning to spend $[illegible] million in 1980 for 47 robots that will carry out such tasks as spraying the coatings on refrigerators, and over the next ten years it plans to have as many as 1,000 robots conducting a range of assembly operations in its appliance plants. The reason? This year's outlay will save $2.6 million a year in labor costs, and the company ultimately expects to replace half its 37,000 assembly workers with robots.[16]

Although it is difficult to get a clear picture of just how many robots are in use worldwide and what they are doing, most analysts agree on two things: Japan leads the world in the number of robots installed, and the global population of robots is expanding fast. According to most estimates, Japanese factories boast about half the world's installed robots, and this year Japanese robot manufacturers are expecting to do more than $300 million worth of business. By 1985, according to one projection, the market for robots in Japan could reach $1.3 billion. American robot makers are also doing a brisk business: in 1980, sales are expected to reach close to $100

20 million, order books are full, and waiting periods have grown to at least one year.[17]

Two developments on the horizon are likely to give a substantial boost to the use of robots. The first is the development of machines equipped with vision or touch sensors. And the second is the potential entry of some giant electronics firms such as International Business Machines (IBM) into the business of making industrial robots, a step that several industry analysts are now predicting.

"Engineers in a dozen or so research laboratories around the world are nearing one of the ultimate goals in manufacturing technology," suggests British science journalist Peter Marsh. "The researchers are putting the finishing touches to robots that can 'see' well enough to assemble small devices, such as electronic motors or tape recorders, in the same way as human workers." The key to this development is the use of powerful microprocessors and computer memory to link the image produced by a camera to the operations of a robot.[18]

Some prototype "seeing" robots are already in existence. Westinghouse, with some financial backing from the U.S. National Science Foundation, is setting up a trial production line to make small electric motors with a staff of six robots, three of which are equipped with vision. Texas Instruments uses some seeing robots to assemble calculators, and IBM is reported to be using similar machines to make up printed circuit boards. Parallel research efforts that are aimed at equipping robots with sensitive pads that would enable them to discern objects by a sense of "touch" are also well along in several laboratories.[19]

The development of this new generation of more intelligent robots will greatly extend the number of jobs that machines can perform, for they would be used to carry out more intricate tasks than today's robots can tackle. A Fiat executive suggested to *Business Week*, for example, that with sensory robots it would be possible to reduce the

"It is now possible to devise a factory in which computer-controlled equipment carries out an entire production operation."

number of workers required in some plants "down to about 10 percent of what you have today."[20]

Robots are not cheap, however. The current generation of relatively dumb machines starts at around $35,000 for a model that can be programmed to carry out several tasks. One equipped with vision or touch sensors would cost at least $75,000. But even at these prices, robots can represent an attractive economic proposition. According to Joe Engelberger, president of a large American robot company, an average robot costs about $4.80 per hour to operate when it is used for 16 hours per day. That is less than half the wage earned by a worker on an assembly line.[21]

As the market expands, and as the cost of microelectronic controls continues to drop, the price of robots is expected to decline. This trend will be greatly accelerated if some of the major electronics companies enter the business, for manufacturing costs are likely to go down as production volume rises. According to a projection by a leading Wall Street investment analyst, as many as 200,000 robots per year could be sold by the end of the eighties if the major computer makers enter the business.[22]

The growing sophistication and flexibility of microelectronically controlled machine tools and robots will mean a large range of jobs can be automated. But the ultimate impact of these intelligent machines will extend well beyond the piecemeal automation of individual tasks, for it is now possible to devise a factory in which computer-controlled equipment carries out an entire production operation.[23]

In such a plant, a large central computer would guide the operations of minicomputers and microprocessors that in turn control the operations of machine tools and robots. The design of parts and of finished products is carried out with the aid of a computer, which then generates a program to control the machine tool that will manufacture the product. As the European Trade Union Institute tersely notes, "the highly skilled toolmaker's job is thereby completely eliminated."[24]

Although such a plant sounds like something dreamed up by science fiction writers, it may not be too far away. The production of integrated circuits, for example, incorporates some of these features, for computer-generated circuit designs are transferred onto masks that govern the automated manufacturing process. The U.S. Air Force is also coordinating a program in which about 80 aerospace companies are attempting to apply computer-aided design and manufacturing techniques to the production of aircraft and missiles. And in Japan, the Ministry of Trade and Industry is sponsoring an effort to develop a completely automated production facility by 1985.[25]

Many production processes will not lend themselves to such automation, however, and the fully automated factory will require high levels of capital expenditure. But as microelectronic technologies continue to improve the versatility and reduce the costs of robots and other machine tools, individual elements of the fully automated factory will be introduced. A study conducted for the British Government recently concluded, for example, that "the automation of existing control operations in factories could proceed quite rapidly."[26]

The Electronic Office

Information is the raw material of office work. In one way or another, the majority of the labor force in industrial countries is involved in the processing, storage, retrieval, or communication of information. The microelectronic revolution will alter the way this information is handled. Intelligent office machines that incorporate microelectronic devices are beginning to provide the basis for speeding up and automating many office tasks.

The incentive to automate office work is obvious enough. Although office employment has been increasing rapidly in recent decades, the productivity of office workers has remained relatively static. According to one estimate, while the productivity of office workers rose by about 4 percent between 1960 and 1970, that of blue-collar workers almost doubled. The reason is simple: factory workers are backed by increasingly sophisticated technologies, yet most office workers rely on equipment and technologies that have changed little in 50 years.[27] 2

The average factory worker operates about $25,000 worth of machinery, while the average office worker uses less than $2,000 worth of typewriters, filing cabinets, copiers, and other equipment. But the rapid proliferation of smart machines, such as small computers, word processors, facsimile machines, and computerized telephone terminals, is beginning to change this pattern of expenditure.

This new generation of office equipment will encourage a shift from paper to electronics as the basic medium for handling information. At present, office communications are largely limited to paper documents that are sent through the mails and filed in bulky filing cabinets. But the growing use of computers and other electronic equipment means that more and more information is being converted to electronic signals, transmitted over telephone lines, and stored in electronic data banks. Like the unstaffed factory, the electronic office is far from becoming a familiar sight; but the building blocks of the office of the future are rapidly being put in place.

Consider, for example, the recent surge in sales of small computers and their use in a broadening array of offices. The Electronic Industries Association (EIA), an American trade organization, has reported that some 138,000 minicomputers—defined as machines priced from $5,000 to $40,000—were sold in the United States in 1979 alone. By 1984, industry analysts predict, sales could nearly triple, to 382,000 machines per year. Another study reported by EIA found that the sales of computers priced below $10,000 apiece, which includes

4 home computers as well as business machines, climbed from $276 million in 1978 to $658 million in 1979, and are headed toward a projected $2.4 billion in 1984. Just a decade ago, there were reckoned to be less than 100,000 computers in use worldwide.[28]

The availability of small, relatively cheap computers, founded on microelectronics, has not only brought computing power within the reach of small organizations, but it has also distributed it more widely around large enterprises. Until recently, virtually all computing was confined to the central data-processing departments of large companies, but now small, powerful computers can be found in sales departments, helping in sales planning; in budget departments, performing cost accounting and budget planning; in stockrooms, keeping tabs on inventories; and in planning departments, preparing forecasts and projections.

The nature of large, central computers has also changed under the influence of microelectronics. Not only have they become smaller, more powerful, and cheaper, but the way they are used differs as well. Until a few years ago, central computers were linked to remote terminals that essentially fed instructions to the computer and received output from it. Now the terminals themselves are usually equipped with microprocessors and memory stores, which turns them into minicomputers in their own right. This means most computing can be carried out locally and data can be fed into or retrieved from the central computer's data banks.

The growing use of small computers has thus already resulted in a dispersal of computing power, more traffic in electronic data transmissions between small computers and central data banks, and an increased amount of electronic storage of information. The arrival of the word processor has had an even broader impact.

Electric typewriters have long been available with limited memory facilities that enable text to be edited without having to be completely retyped. The word processor extends those functions and provides many more. Closely related to computers—indeed some word processors are small computers with additional capabilities—word processors are built around an electronic keyboard, a microprocessor, and a microelectronic memory. Text entered through the keyboard is displayed on a screen and converted to electronic signals that are stored in the machine's memory. The microprocessor permits the text to be edited, deleted, added to, and moved around without each draft having to be retyped separately. The machine is usually connected to a printer—often a built-in typewriter—and a clean, typed draft is available at the push of a button.

When used to prepare documents, such as legal briefs, letters, and similar manuscripts, a word processor can at least double typing efficiency. And when the machine produces standard letters, all or part of which are stored in its memory, efficiency can be boosted by about 400 percent, according to some studies. Word processors have only been around for a few years, but they are already well-established in many offices. In 1978, there were estimated to be 100,000 word processors in Europe and 400,000 in the United States. In 1980, U.S. sales alone are expected to climb past $1 billion—more than 100,000 separate machines—and a $2-billion-per-year market is expected to develop by 1983.[29]

Along with small computers and word processors, microelectronic technologies have spawned a whole host of other smart business machines. Facsimile machines, for example, can "read" printed text and convert it to electronic signals that are transmitted over telephone lines to another facsimile machine capable of reconverting them to the printed form—a process akin to long-distance photocopying. Although such machines have been available for some years, they have recently become much faster and smarter. Some of the newer versions, for example, can store the text in their own memory banks, and wing electronic copies to several other receiving machines. By 1983, according to an estimate by the Stanford Research Institute, some eight billion pages of text will be transmitted between facsimile machines in the United States.[30]

High-speed printers that incorporate microprocessors can produce thousands of lines of type per minute when coupled to the output of a word processor or a computer. Just as a photocopier often serves the needs of a whole office, a single high-speed printer can handle the output of several word processors, some of which can be located far away from the printer and be linked to it through the telephone system. And the telephone system itself is becoming far more flexible with the advent of intelligent telephones that can hold incoming calls, remember frequently dialed numbers, and route calls to an alternative number.

All of this technological wizardry is being pushed along by some of the biggest names in the corporate world. IBM, Xerox, and even Exxon are developing complete lines of office equipment in the United States; in Europe, such industrial giants as Siemens and Philips have joined the fray; and in Japan, giant electronic conglomerates such as Hitachi are pursuing the technology. Scores of smaller firms are also producing electronic office equipment, computers, and peripheral devices that can be linked to existing machines. All this activity, it should be noted, has blossomed since microelectronics came of age less than a decade ago.

These new business machines on their own can increase the efficiency with which some office tasks are carried out. But the full impact of this flood of office technology will only be felt when the machines are linked in far-flung networks through which information can be transported, stored, and processed. The potential merger of computing, word processing, and telecommunications is at the heart of the much-touted information revolution.

In theory, for example, it is possible to transmit information between word processors, computers, facsimile machines, and so on through the telephone system, bypassing the cumbersome and paper-clogged mails. Electronic cash registers—close cousins to small computers and word processors—can be hooked up to bank computers to debit a customer's account directly, eliminating the need for checks or

"The potential merger of computing, word processing, and telecommunications is at the heart of the much-touted information revolution."

cash. They can also record sales of individual items and relay the information to a central computer that looks after stock control. And computers, word processors, and even modified domestic television sets can be linked to electronic data banks to receive information electronically "without the services of filing, library, and secretarial staff," the European Trade Union Institute notes.[31]

Such developments are not just remote technological possibilities. They are all feasible now, and most of them are in limited operation. Whether they will become widespread depends, however, on a range of technological, economic, social, and legal factors. One important consideration is that a large number of intelligent machines must first be installed, for, as one observer has tartly pointed out, "it is no use writing letters electronically if the people to whom they are sent do not have electronic mail terminals to receive them." Another requirement is that large amounts of information currently stored on paper must be transferred to electronic data banks. So far, sales of machines and the development of electronic information storage are expanding rapidly. There are more fundamental problems associated with existing telecommunications networks, however.[32]

The widespread communication of information between intelligent machines will require substantial changes to existing telephone systems. Built to carry voice signals, the systems will be hard pressed to transmit the signals and the volume of information generated by computerized machines. They also transmit the information far too slowly for most data communications uses. Upgrading the systems by installing computer-controlled exchanges will greatly improve their ability in these respects, but it will be a long and costly job. Nevertheless, it will be essential if some of the projected uses of the new office machinery, such as the widespread transmission of mail electronically, are to be based on the telephone system.

An alternative approach is to set up purpose-built satellite communications systems to handle data traffic. Some newspapers, such as the *Wall Street Journal*, already transmit pages via satellite to printers in several locations, enabling them to print and distribute the paper nationwide. And two private corporations, Satellite Business Systems—a group consisting of IBM, Comsat General, and Aetna Life Insurance—and Xerox, are planning to set up satellite communications systems for private subscribers in the United States, for use in both voice and electronic data communications. Both these systems are likely to be expensive, however, which will limit their use to large corporations. And both have run into technical problems that may delay their introduction until the mid-eighties.[33]

The expanded use of electronic business machines also suggests that there will be sweeping changes in the way that some offices are structured, with work increasingly being diverted to the new machinery, some jobs being eliminated, and other jobs being reclassified. All this is likely to cause major upheavals and changes in working conditions. As a report by Working Women, an American association of office workers, points out, "because the new technology is being developed to computerize the very flow of work in the office, its potential impact is qualitatively different from previous office equipment which 'mechanized' or 'automated' routine tasks."[34]

Malcolm Peltu, a British communications consultant, has noted, however, that "for all their brilliance, some of the new devices and experiments still have a long way to go to achieve [the] objective of making the electronic office *at least* as effective as present ones. Paper, typewriter, copier, pen, wire trays, dictating machines and battered old filing cabinets are reliable, proven methods of running an office in a way that people can understand." Adds the *Financial Times:* "it is a sobering antidote to futuristic speculation to realize that in Britain only one office in four has a photocopier, one in 10 a data processor, and one in 40 a word processor. It was not until five years ago that sales of electric typewriters overtook those of manual machines."[35]

Nevertheless, the sales of electronic office equipment are expanding so fast, and the technology is being pushed so rapidly by such an immense amount of industrial might, that office work is bound to

"The expanded use of electronic business machines suggests there will be sweeping changes in the way some offices are structured."

change markedly in the coming years. "1984 looks a good bet as the year the information revolution starts," suggests Peltu.[36]

Chips and Jobs

Fears of massive unemployment have greeted technological changes ever since the Industrial Revolution. Far from destroying jobs, however, rapid technological advance has generally been accompanied by high rates of job creation. The quarter-century following World War II, for example, saw the industrial economies flooded with new technologies, while the number of jobs increased steadily and unemployment shrank to exceptionally low levels. Yet there is good reason to take seriously the recent outpouring of concern that microelectronic technologies will have a fundamental impact on both the number and types of jobs in the industrial world in the coming decades.

Central to these concerns is the pervasiveness of microelectronics. The microelectronic revolution could affect employment in enterprises ranging from steelworks to banks; no technology in history has had such a broad range of potential applications in the workplace. Another source of concern is that products incorporating microelectronic devices generally require significantly less labor to produce than the goods they replace, a fact that extends the employment implications of the technology well beyond its direct impacts on automation. And a third reason for apprehension is the speed with which the technology is advancing. Although microelectronic controls will not sweep through the industrial world overnight, most experts expect them to be firmly established in production processes, products, and daily activities over the next two decades.

Set against these concerns, however, is the fact that microelectronic technologies hold the promise of increased productivity over a broad range of industrial enterprises. In theory, this should lead to enhanced economic growth, which in turn will translate into new jobs. That, in essence, is how technological change in the past has operated to increase employment in the industrial world—at least until the mid-seventies. Put crudely, the extra production made possible by technological changes coincided with rising wealth and increased demand for manufactured goods and services, a combination that led to high rates of economic growth and near-full employment. But there are good reasons why those historical trends may not provide a reliable guide to the future. Both the hopes and the concerns surrounding microelectronics must be seen in the light of other economic forces and in the context of the deep structural changes that have been taking place in the industrial labor force over the past few decades.

As is well known, a combination of technological changes and economic and social pressures led to a sharp reduction in the agricultural work force in the developed world over the past half-century. In every major Western industrial country, the agricultural labor force now represents less than 10 percent of the working population; in the United States and Britain, the proportion is below 4 percent. While the number of agricultural workers has decreased, however, output has generally risen substantially—a phenomenon that has been dubbed "jobless growth." Now there are indications that in many parts of the world jobless growth is occurring in manufacturing industries as well.[37]

According to studies by the Science Policy Research Unit in Britain, employment in manufacturing industries in most Western industrial countries rose steadily in the fifties, began to tail off in the sixties, and declined in the seventies. At the same time, output, while fluctuating in tune with recessions, has increased. "The phenomenon of jobless growth has now become established in the goods producing sectors of the advanced industrial countries caused mainly through technological change," the study suggests. Underlying this trend is the fact that investment in new production technologies has largely sought to rationalize and streamline production processes rather than to expand output at a time of depressed demand and high wage rates. This was especially true of investments in new automobile manufacturing technologies in Britain and the United States during the late seventies.[38]

While these job and investment patterns have been developing, employment in the tertiary sector of the economy—finance, insurance, government, services, and so on—has been expanding rapidly. (See Table 1.) In the United States, for example, 92 percent of the new jobs created between 1966 and 1973 were in this sector, and in every major industrial country the tertiary sector now accounts for at least half the labor force.[39] It is important to note that it is the productivity increases in the manufacturing industries that have themselves created the economic growth that in turn led to the increased demand for the services of the tertiary sector.

Table 1: Average Annual Growth in Employment in OECD Countries, 1965-75

Sector	1965-70	1970-75
	(percent)	
Agriculture	− .5	− .5
Industry	+ .4	− .1
Tertiary	+1.2	+1.3
Total Civilian Employment	+1.1	+ .8

Source: Organisation for Economic Co-operation and Development, *Medium Term Strategy*.

This transition from agriculture to industry, and more recently to tertiary sector employment, has not been smooth or even. Some industries have continued to expand their employment, while others, such as steel and textiles, have contracted. Within the service sector, too, growth rates have been highly uneven, with sharp increases in government employment in most countries and steady gains until recently in banking, insurance, and similar occupations.

During the seventies, the sharp rises in energy prices, high rates of inflation, and slow rates of productivity growth have had deep and very obvious impacts on levels of employment. At the end of the seventies, unemployment stood at more than six million in Europe, about 6 percent of the American work force was out of work, and even in Japan, where lifetime employment guarantees are common, the official total of unemployed reached one million.[40] These high unemployment totals are in part due to policies designed to dampen demand in order to bring down rates of inflation. Yet a return to high levels of demand for the products of some labor-intensive industries, such as steel and shipbuilding, is considered unlikely even if inflationary pressures moderate, as the market for these products is reaching saturation.

It is against this background that the microelectronic revolution must be assessed. Since the technology is less than a decade old, it is impossible to draw conclusions about the specific impact on job levels. There is already sufficient experience to reach some general conclusions, however.

First, it is clear that microelectronic technologies will create jobs in those industries manufacturing novel electronic products. The $4 billion now being lavished on electronic watches, calculators, games, and other microelectronic products has spawned a whole industry that did not even exist a decade ago. According to a projection by the American consulting firm Arthur D. Little, the manufacture of these items, together with computers and other electronic equipment, could create about one million new jobs between 1977 and 1987 in the United States and Western Europe combined. About 1.5 million people are now employed in the electronics industry in the United States.[41]

But these jobs will not represent net additions to the work force, for they will be offset to some extent by job losses in the manufacture

"The Swiss watch industry lost 46,000 jobs in the seventies as customers switched in droves to electronic watches made in the United States and Japan."

of goods with which the new microelectronics-based products are competing. The Swiss watch industry, for example, lost 46,000 jobs in the seventies as customers switched in droves from mechanical timepieces to electronic watches made in the United States and Japan. Seventeen Swiss watch manufacturers went bankrupt in this period.[42]

Moreover, as manufacturers incorporate microelectronic devices into their products in place of mechanical or electromechanical parts, their labor requirements often plummet. The reason is that one tiny piece of microelectronic circuitry can substitute for hundreds of moving parts, which eliminates the labor required to make those parts as well as the labor involved in assembling them. An electronic telex machine manufactured by the West German company Standard Electric Lorenz, for example, has one microprocessor in place of 936 moving parts; its manufacture requires only about 18 hours, compared with 75 hours for an electromechanical telex.[43]

The European Trade Union Institute has surveyed the job losses reported in companies that have recently begun to manufacture microprocessor-controlled goods in place of older equipment. It found a substantial reduction in labor requirements. Among the firms most affected are the manufacturers of cash registers. The American company National Cash Register (NCR) noted in its 1975 annual report, for example, that an electronic cash register requires only 25 percent as much labor to produce as its mechanical or electromechanical counterpart. As a result, NCR reduced its work force in the United States from 37,000 to 18,000 between 1970 and 1975, the West German branch of NCR shed 3,800 workers between 1974 and 1977, and employment in the firm's Dundee plant in Scotland dropped from 3,000 in 1975 to 1,000 in 1978. Manufacturers of telecommunications equipment are similarly affected. Telecommunications Ericsson in Sweden reduced its work force from 15,000 to 10,000 between 1975 and 1978, and employment in telecommunications manufacturing in Britain dropped from 88,000 to 65,000 during the same period.[44]

A committee of the Organisation for Economic Co-operation and Development, studying the relationship between technological change and economic growth, has reached similar conclusions about the employment impact of the change from mechanically controlled products to those based on microelectronics. The committee surveyed the plans of major electronics corporations and found that few of them expected to increase employment over the next few years. "Electronics has dramatic growth prospects ahead in the next decade. If this industry expects to achieve such growth with little or no increase in employment," the committee noted, "then the question may be asked where in the manufacturing sector is . . . growth in employment to come?"[45]

Many of the industries that have traditionally been leading employers, such as those producing automobiles, chemicals, appliances, and so on, are likely to incorporate microprocessors and small computers into production processes to improve efficiency and productivity. Already, the introduction of robot welders in automobile assembly has resulted in sharp reductions in jobs and consequent increases in productivity in a few plants. According to one study, the General Motors plant in Lordstown, Ohio, boosted production by 20 percent but reduced its work force by 10 percent after the introduction of robot welding machines. New automation technologies, including computer-controlled welding machines, in BL Ltd's Longbridge plant in England are expected to raise productivity from the current level of 16 cars per worker per year to 23 by late 1980 and ultimately to 32. That would bring their productivity close to that which prevails in Japan's highly automated plants. And such machines are not limited to heavy, dangerous tasks: a microprocessor-controlled machine has been developed for screwing light bulbs into the instrument panels of General Motors cars.[46]

A well-publicized area in which electronic technologies have decimated blue-collar jobs is the printing industry. In West Germany, for example, employment among printers dropped by 21.3 percent between 1970 and 1977, while productivity per hour rose by 43.5

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percent. Many American newspapers have also gone over to computerized typesetting in the past few years and have seen sharp boosts in the productivity of their print workers. The *New York Times*, for example, reduced its printing staff by 300 in 1978 when it introduced the new technology, and the Rhode Island *Journal Bulletin* decreased the number of workers in its composing room from 242 in 1970 to 98 in 1978, a figure that is scheduled to drop further to 54 in 1980.[47]

The use of microelectronics in the production of television sets has had a two-pronged effect on employment. First, integrated circuits have replaced many individual components in recent years, thereby reducing assembly operations. And second, computerized assembly lines have been developed. According to a report by Clive Jenkins and Barrie Sherman of the Association of Scientific, Technical and Managerial Staffs, a British trade union, seven Japanese color television manufacturers reduced their combined work force from 48,000 to 25,000 between 1972 and 1976, while they increased production by 25 percent. A British television maker, Thorn Electrical Industries, followed the Japanese methods, and cut its labor force in half.[48]

This level of job loss will not be felt in every manufacturing industry, but the potential range of microprocessor-based automation is very broad. A study by the National Electronics Council in Britain, for example, has suggested that the industries most ripe for automation by computers include metal and plastic fabrication, instrument engineering, electrical engineering, shipbuilding and marine engineering, vehicles, electronic components and assembly, office machinery, aircraft, and printing and publishing.[49]

The use of microprocessors in manufacturing industries will essentially intensify the jobless growth that has been taking place in industrial countries in recent years. The key question, therefore, is whether the number of jobs in the tertiary sector will continue to expand to absorb the projected growth in the labor force. There are two chief reasons why the answer could be negative. First, the number of jobs

6 in government offices—an area of substantial employment growth in recent years—may not expand much more because of demands in virtually every country to reduce public expenditure and to cut government payrolls. Second, most observers have predicted that the most far-reaching impacts of microprocessors will be felt in offices and in such service activities as retailing and maintenance work.

The use of computers and other intelligent machines will lead to increased employment in some areas, it should be noted. Computer programming, for example, is a labor-intensive activity that is a likely source of many thousands of new jobs in the eighties. Demand for programmers is already outstripping supply, and some analysts have even suggested that this shortage could constrain the growth in the use of computers in the coming years. But in most other areas of the tertiary sector, microelectronics is likely to lead to slower rates of employment growth or even to job losses.[50]

In areas such as insurance and banking, which are labor-intensive occupations that rely primarily on printed paper for their transactions, the application of electronic technology could have a major impact. Already, growth in employment in these industries in Europe

Table 2: Annual Change in Employment in Banking and Insurance in Five European Countries, 1964–77

Country	1964–74	1974–77
	(percent)	
Belgium	10.2	7
Denmark	6.1	7
France	6.3	-.1
United Kingdom	3.3	.6
West Germany	3.7	−1.9

Source: European Economic Commission.

has begun to tail off, while their business carries on expanding.[51] (See Table 2.) Some observers are therefore suggesting that the jobless growth apparent in agriculture and manufacturing is now occurring in these two sectors.

The most widely publicized of such projections was made in a report to the President of France, which warned that 30 percent of the jobs in the French banking and insurance industries could disappear during the eighties as more and more work is consigned to computers.[52] Such projections should not be treated lightly. An indication of the type of transformation that can be wrought by the new office machines can be seen in the work of a major British insurance company. According to a report by Colin Hines and Graham Searle of Earth Resources Research:

> The British insurance company, Friends Provident, is already developing its own internal services by transacting insurance through a nationwide network of display terminals, which also provide for the composition and printing of policy documents and the automatic handling of premium payments. This 'instant policy' system has, they claim, virtually eliminated all paper work from what was a notoriously paper-bound process. It used to take a minimum of three weeks to produce even a straightforward policy from the customer's proposal form, whereas with the new system a policy can be issued in three minutes. The Services Manager of Friends Provident anticipates staff savings of 40 percent, which will pay for the cost of installing the system.[53]

A similar transformation in the United States has taken place in the letter-of-credit department of Citibank's Wall Street office. Richard Matteis, a Citibank vice president, describes how the company automated the handling of letters of credit using a variety of computer-controlled equipment and record storage: "Where it once took days, 30-odd separate processing steps, 14 people, and a variety of forms, tickets, and file folders to process a single letter of credit, it now requires one individual less than a day to receive, issue, and mail out a letter of credit—all via a terminal that is fully online to a minicomputer-based system."[54]

The introduction of word processors, computers, and other intelligent business machines will not always cause job losses. In many offices, the machines will be used to improve quality and upgrade services without displacing people. But several studies have suggested that the widespread use of these machines will ultimately lead to small job losses in large numbers of offices. A much quoted, but unpublished, study by Siemens Corporation in West Germany, for example, has suggested that some 40 percent of the office jobs in that country could be automated.[55]

Outside the office, microelectronics is likely to affect employment in service occupations ranging from stock handling to mail delivery. The ability to link cash registers to a central computer that monitors stock levels and automatically initiates reordering, for example, will reduce labor requirements in retail operations. As more and more messages are relayed electronically between word processors and computers, a reduction in the amount of paper-based mail can be expected, and hence in the number of people needed to deliver it. The increasing use of microelectronic controls in products such as automobiles could change not only the types of maintenance jobs, but also the tools needed to carry them out. A garage lacking highly sophisticated computerized diagnostic equipment, for example, is unlikely to be able to service a computer-controlled automobile.[56]

While it is difficult to determine just how many jobs will be lost or gained by the introduction of microelectronics, Clive Jenkins and Barrie Sherman have attempted to draw up estimates for specific industrial groups in Britain. Their overall conclusion is that over the next quarter-century, almost one-fourth of the jobs in the industries they surveyed are likely to disappear. About 5 percent of them would be lost by 1983, they suggest. A more detailed examination of the probable impact of microelectronics on employment in

"If the chief impact of microelectronics is felt in offices, women workers are the ones who will bear the brunt of the new technology."

an industrial region in Manchester, England, reached the conclusion that only about 2 percent of the jobs in the area would be lost by 1990 as a direct result of the use of microelectronic technology in both products and processes. The authors of that study, which was conducted at the University of Manchester, warned, however, that "it is in the 1990s that the job losses due to microelectronics will really make themselves felt."[57]

Microelectronics will affect not only the number of jobs in industrial countries, but also the type of jobs available. The early use of robots on assembly lines has largely been in dangerous, dirty, and difficult occupations that few people are lining up for. But as automation extends into design shops and machine rooms, highly skilled occupations could be affected. And, at the other end of the scale, the use of intelligent office machines and electronic information storage is likely to eliminate many filing and routine clerical jobs. Microelectronics thus has the potential to decrease skill requirements in some jobs and increase them in others.

The types of jobs most likely to be affected, according to a study conducted for the British Government, are "proof-readers, library assistants, mail carriers, telegraph operators, draftsmen, programmers, accountants, financial analysts, administrators, secretaries, billing clerks, keypunchers, cashiers, filing clerks, meter readers, shipping clerks, TV repairmen, plateprinters, telephone repairmen, light electricians, machinists, mechanics, inspectors, material handlers, warehousemen, sales clerks, compositors."[58] Moreover, if, as most experts are predicting, the chief impact of microelectronics is felt in offices, women workers are the ones who will bear the brunt of the new technology.

In addition to its affect on levels and types of jobs, the use of computers and microprocessors to control production lines and office work will lead to increased control over the work force itself and the reorganization of jobs around the dictates of the new technology. Computers not only control machines, but in many cases they are used to control the speed of production lines and the routing of work in factories and offices. Harley Shaiken, a consultant to the United Auto Workers Union in the United States, describes an automobile plant in which a computer-controlled assembly line had been installed: "The system links a large central computer to a microprocessor on a machine. When the machine cycles, it is recorded in [the] central computer. When a machine doesn't produce a part in its allotted time, it is immediately obvious to more than the computer: that information is displayed in the foreman's office and recorded on a computer printout." Under this system, Shaiken says, "the foreman no longer decides to discipline the workers. He merely carries out the 'automatic' decisions of the system."[59]

The microelectronic revolution is thus likely to have major impacts on the number and types of jobs available in the industrial world over the next few decades. But every expert who has studied the potential employment impact of microelectronics has reached the same conclusion: more jobs will be lost in those countries that do not pursue the technology vigorously than in those that do. The reason is that microelectronics will enhance productivity to such an extent that the industries that move swiftly to adopt the technology will have a competitive advantage in international markets.

International Dimensions

With sales amounting to well over $100 billion a year and manufacturing plants spread around the world, the electronics industry has taken its place among the leading sectors of the global economy. For the past 15 years, it has been growing by more than 10 percent annually, and within a decade it is expected to vie with the production of automobiles as the world's largest manufacturing industry. By 1990, according to several projections, the market for electronic goods will have reached about $400 billion a year.[60]

But the economic importance of the electronics industry will extend further than even these huge sums of money indicate. Outputs from

"Rapid technological advances by Japanese companies are beginning to threaten American technological hegemony in some areas."

the electronics industry will form critical inputs into many other industries—changing production processes, speeding up the handling of information, spawning markets for new consumer goods, and improving productivity. Indeed, the Organisation for Economic Co-operation and Development has suggested that "the electronics complex will be the main pole around which the productive structures of advanced industrial societies will be reorganized."[61]

Technological innovation has always played a key role in the world economy. Technological advances in petrochemicals and synthetic materials in the postwar years, for example, deeply affected markets for natural products and stimulated new areas of growth in the industrial countries. But developments in electronics are likely to affect such a broad range of activities that their economic impacts will be unprecedented. The painful experience of the Swiss watch industry in the early seventies is a salutary reminder of just how swiftly microelectronic technology can upset the structure of an important international market.

Faced with these prospects, governments throughout the industrial world have begun to examine the health of their electronics industries and they are devising ways to encourage other sectors of their economies to adopt the new technologies. Since advances in microelectronics lie at the root of the projected growth and influence of the electronics industry, a good deal of attention has been focused on relative international standings in the race to develop and market ever more powerful integrated circuits. Large sums of public money are being poured, directly and indirectly, into this race.

The United States has long dominated the development and marketing of microelectronics. Virtually all the early innovations were made in the United States, and American companies account for more than 70 percent of the world's production of integrated circuits. But the structure of the U.S. semiconductor industry is changing, and rapid technological advances by Japanese companies are beginning to threaten American technological hegemony in some areas.

 The key innovations have mostly been made by a handful of U.S. companies that were established in the sixties with a few million dollars of venture capital apiece. Some of these companies have turned that initial investment into an annual turnover of hundreds of millions of dollars, and they are rapidly climbing up the Fortune 500 list of major American corporations. They are heavily concentrated in a region just south of San Francisco colloquially known as "silicon valley." It used to house plum orchards.[62]

These small innovative companies eclipsed the big electronics conglomerates such as RCA and Westinghouse by moving rapidly into the commercial production of each new technological breakthrough. Today, the bulk of the integrated circuits produced in the United States are still made by semiconductor companies that specialize in the manufacture of microelectronic components and market them to manufacturers of electronic equipment. In 1980, these sales are expected to amount to about $6.3 billion.[63] In addition, IBM, American Telephone and Telegraph, and General Motors manufacture integrated circuits for their own use. A very different structure prevails in Japan and Europe, where the production of integrated circuits is dominated by giant electronics companies such as Hitachi, Nippon Electric, Siemens, and Philips.

In the past few years, however, several American semiconductor companies have been taken over by large corporations, a development that is causing some concern within the industry. The acquired companies, it is feared, will lose flexibility and the ability to make rapid investment decisions when they are under the wing of a large corporation. Some of these takeovers, moreover, have involved foreign companies. Some 15 percent of the U.S. semiconductor industry has been bought up by foreign firms in the past few years. Fairchild Camera and Instrument Company, for example, was bought in 1979 by the French-American oil conglomerate Schlumberger, and the Dutch electronics company Philips has taken control of Signetics. At the same time, some of the leading Japanese semiconductor manufacturers have established U.S. manufacturing facilities. The industrial environment surrounding the production of integrated circuits in the United States is therefore changing fast.[64]

One reason is the escalating cost of establishing new production facilities to meet the projected demand over the next few years. The cost of setting up a new production line to make the most advanced circuits is about $40 million, a far cry from the early days of the business when whole new companies could be established for one-tenth that amount. Consequently, the seven largest American manufacturers are planning to spend more than $1 billion in 1980 on new plant and equipment, and the Chase Manhattan Bank estimates that the U.S. industry will require at least $15 billion in capital investment during the eighties.[65] This thirst for cash is one reason why so many of the original, smaller companies have been willing to accept offers from large corporations.

Over the years, American semiconductor manufacturers have received substantial financial support from the federal government. The Department of Defense and the National Aeronautics and Space Administration funded some of the early research and, more importantly, guaranteed a market for the first integrated circuits produced in the early sixties. It was this support that enabled U.S. microelectronics companies to move quickly into the production of new devices before a commercial market was established, and the experience gained in filling defense and space needs formed a strong basis for later commercial success.

Defense requirements now account for a relatively small share of the market for microelectronics, but the Department of Defense is launching another program that could greatly aid the American industry in developing the next generation of integrated circuits. To the tune of $200 million, the Pentagon is sponsoring an industrial effort to develop what is known as Very High Speed Integrated Circuits (VHSICs)—densely packed microchips that will contain hundreds of thousands of components. The aim is to produce circuits that will perform their electronic functions at extremely high speeds for use in quick-response weapons, missiles, radar, and other military hardware. The techniques involved in making VHSICs are likely to have commercial applications, and they could help to preserve the technological edge of the United States.[66] A few semiconductor manufacturers are wary of getting involved with the program, however, because they fear that it will divert their efforts from developing technologies that are closely related to commercial needs. Moreover, they suggest, the VHSIC program does little to offset the support that Japanese semiconductor manufacturers are receiving from their government.

The Japanese recognized in the early seventies that microelectronics would be a cornerstone of industrial progress in the coming decades, and a government-sponsored effort was launched to foster a domestic computer industry. Measures were taken to protect domestic firms from foreign competition, and a joint government-industry program was initiated to develop the technologies required to make tightly packed circuits. The government put about $250 million into the program, about 40 percent of the total invested.[67]

Although U.S. companies still dominate the world market for all integrated circuits, Japanese companies now provide stiff competition in some products that are at the leading edge of technological development. Japanese manufacturers, for example, produce about 40 percent of the world supply of the current generation of computer memory chips, integrated circuits containing some 16,000 memory cells. They are also starting to market chips containing 64,000 memory cells, as are a few U.S. firms, and at a meeting in early 1980, Japanese engineers stunned their American colleagues by unveiling designs for chips containing 256,000 memory cells. Moreover, because Japanese microelectronics companies are part of large industrial conglomerates, they will have little difficulty raising the capital necessary for large-scale production—an advantage that is enhanced by liberal banking rules that enable Japanese companies to carry a larger debt burden than American companies can.[68]

"By early 1980, several European governments had launched efforts to stimulate domestic microelectronics industries."

While American and Japanese firms have been racing ahead with the technology, European microelectronic development has been lagging. European manufacturers lacked the military and space markets that pulled the technology along in the United States in the early years, and European governments have not moved as quickly or as decisively as the Japanese in sponsoring development of microelectronics. In 1979, European companies produced less than one-third of the $1.6 billion worth of integrated circuits used by European industry. Most of the rest were imported from the United States or bought from European-based American companies. By early 1980, however, several European governments had launched their own efforts to stimulate domestic microelectronics industries, and the European Economic Community has also initiated a modest effort to coordinate some electronics and telecommunications activities among member countries.[69]

The most conspicuous venture so far is the establishment in Britain of a full-fleged integrated circuit manufacturing company with an investment of about $120 million from the British Government. Called Inmos, the company will make computer memory chips that have 64,000 memory cells—the next generation of memory circuits. The idea is to aim the British effort right at the cutting edge of the technology, in the hope that Inmos will capture a healthy share of what is expected to be a booming market for these devices. More importantly, it is hoped that the launching of a British microelectronics company will stimulate greater interest in that country among potential users of integrated circuits.[70]

The West German Government is pumping about $25 million per year into research and development efforts designed to produce state-of-the-art integrated circuits. And the French Government is using its muscle in the marketplace to stimulate the development of domestic semiconductor companies. To meet military and telecommunications needs, government agencies buy about half the integrated circuits used in France, and they give priority to French firms and to French-American joint ventures in their contract awards.[71]

6 There is thus vigorous competition among the industrial countries for a share of the $10 billion integrated circuit market. The stakes are high, for the market is expected to expand to at least $25 billion by the mid-eighties, and there will be considerable cross-fertilization between producers and users of microelectronics. But the stakes are even higher in the race to incorporate microelectronic devices into products and processes, for the secondary economic impacts will be enormous. The United States is currently the world's largest user of microelectronic devices, although Japan is steadily increasing its share of world consumption.[72] (See Table 3.)

Table 3: Distribution of Semiconductor Use Among OECD Members, 1965-78

Area	1965	1970	1974	1978
		(percent)		
United States	66	53	48	46
Western Europe	18	22	25	23
Asia	14	22	24	28
Others	2	3	3	3

Source: Charles River Associates.

The U.S. dominance arises partly from the fact that American computer firms—the largest users of microelectronics—have a commanding position in the world market. IBM alone accounts for more than half the worldwide sales of computers. But in other areas too, such as consumer electronics, industrial control equipment, and office machinery, American companies have moved rapidly to incorporate microelectronics into their products. Most of this development has taken place under the pull of commercial forces, as suppliers of microelectronic devices work closely with electronic equipment manufacturers. In addition, the U.S. Government has supported research and development efforts to improve the capabilities of robots and computer-controlled machine tools, under the sponsorship of the National Science Foundation and the National Bureau of Standards.

In Japan, there is a concerted effort to move microelectronic technology into a variety of industries as quickly as possible. "Japan is undoubtedly the country with the most consistent medium- and long-term programme for industrial electronics, ranging from components through automated control systems, to capital goods," suggests the Organisation for Economic Co-operation and Development. Japan already boasts at least half the world's working robots, and a vigorous program supported by the Ministry of International Trade and Industry is racing to develop new industrial automation techniques. Japanese steel, automobile, and television assembly plants are among the most highly automated in the world, which is one reason why they have captured such a large share of the world market for these goods.[73]

European governments are also sponsoring ambitious programs to encourage their domestic industries to adopt new microelectronic technologies. In Britain, for example, the government has established, in addition to Inmos, a company to design and manufacture electronic office equipment, and it is putting about $100 million into a program designed to boost awareness of microelectronics and to assist British industry in using the techn. logy. France, Italy, and West Germany have launched similar efforts. All told, European governments are spending about $1 billion to stimulate domestic production and use of microelectronic technology, and private industry is investing about the same amount. It is worth noting, however, that in the United States IBM alone invests more than $1 billion each year in research and development.[74] The Europeans clearly face some difficulties in trying to overtake the long lead of the United States and to close the lengthening gap between themselves and Japan in the development and application of microelectronics.

The European, Japanese, and American policies are all aimed at achieving the same goal: to protect domestic industries against the threat of foreign competition in manufactured goods by stimulating innovation in new products and processes. Domestic firms, it is hoped, will be able to claim a share of the unfolding markets for new high-technology products, and to preserve their share of the markets for existing products by upgrading production processes. Clearly, these moves have important implications for developing countries, which are also hoping to expand their share of markets for manufactured goods. Yet the impact of the microelectronic revolution on the Third World has so far received scant attention. The Brandt Commission report on North-South relations failed even to mention the new technologies, for example.

Microelectronic technology is likely to affect the prospects for developing countries in two chief ways. First, the automation of factories in the industrial countries through microprocessor-controlled machinery and computerized assembly may erode the comparative advantage that developing countries, with their lower labor costs, now hold. And second, if the electronics industry does indeed become a stimulus for growth across a broad spectrum of other industries, its concentration in the advanced industrial countries is likely to increase the gap in wealth between rich and poor countries. Juan Rada, a consultant to the International Labour Office, has suggested, for example, that "the advanced countries now control an all-pervasive technology which, while changing their productive and service infrastructures, is also reinforcing one of their traditional advantages: science and technology."[75]

These impacts will differ greatly from industry to industry. Howard Rush and Kurt Hoffman of the University of Sussex have argued, however, that two of the industries on which developing countries have built much of their export earnings—textiles and electronics—could be deeply affected by the new technologies. Textiles, garments, shoes, and leather goods account for more than 40 percent of the exports of manufactured products from Hong Kong, Singapore, South Korea, and Taiwan, and more than half the manufactured goods exported from many less-developed countries. Growth rates of

"These technological changes are laying the foundation for a much less labor-intensive process that will erode the advantage of cheap labor in developing countries."

about 20 percent a year in these exports were not uncommon in the sixties and early seventies, but they have slowed in recent years and more modest annual increases of about 5 percent have been projected for the eighties. "With the potential diffusion of new microelectronics technologies, however, even these estimates must be re-examined," suggest Rush and Hoffman.[76]

The automation of textile manufacturing is proceeding rapidly in the United States, for example. The industry there is expected to spend about $2 billion a year during the eighties on new equipment, some of which will be computer-controlled. As a result, as many as 300,000 relatively low-paid jobs could disappear in American textile plants by 1990 while the United States preserves or even increases its share of world textile production. A spinning mill recently opened in the north of England indicates the labor-saving potential of the new technology in textile production: with a labor force of only 95 people and highly capital-intensive equipment, it will produce as much as three plants formerly did with a combined work force of 435.[77]

The manufacture of garments has always been a labor-intensive business in which developing countries have long enjoyed a comparative advantage. But new technologies are cutting into labor requirements there as well. A computerized system for laying out patterns on material, combined with electronically controlled laser cutting, has reduced skilled labor requirements in one British plant from 200 to 20 people. And similar technological advances have taken place in sewing clothes together, with the development of microprocessor-controlled sewing machines. Although fully automated garment production is still a long way off, these technological changes are laying the foundation for a much less labor-intensive process that will erode the comparative advantage of cheap labor in developing countries.[78]

Electronic goods are the third largest category of manufactured exports from the developing countries. Virtually all of them are under the control of multinational corporations, which ship electronic components to the developing world and re-import finished products.

Such "offshore" assembly extends from the delicate process of attaching fine wires to integrated circuits so they can be connected to circuit boards, to the final assembly of television sets and other products. Although this business has brought substantial export earnings to several Asian and Latin American countries, it has also brought many problems. It involves low-skilled and low-paid labor, highly regimented work, and hours of peering through microscopes —a requirement that, according to one report, means that "virtually anyone who stays on the job more than three years must eventually wear glasses."[79]

Even the job creation involved in this arrangement may slow down under the impact of new automation technologies, however. The testing and soldering of integrated circuits is now being automated, for example, and recent investments in new plants have been made in the industrial countries rather than in the developing world. This trend was anticipated several years ago, for a 1977 article in *Scientific American* suggested that "the traditional cost-saving technique has been to employ less expensive overseas labor for the labor-intensive packaging operation. As the cost of overseas labor rises and improved packaging becomes available, overseas hand labor is gradually being supplanted by highly automated domestic assembly." Japanese semiconductor companies have long used highly automated processes to package integrated circuits in Japan.[80]

In the manufacture of electronic goods, the reduction in labor requirements by Japanese television companies—a 50 percent drop in the work force during a period when output rose by 25 percent—points the way to future trends. Such computerized assembly is "expected to become a major determinant of international competition" in this industry, suggest Howard Rush and Kurt Hoffman. The result is likely to be less incentive to locate assembly plants in developing countries.[81]

The clothing and electronics industries are especially important because they figure prominently in the export earnings of developing countries, but a similar erosion of the comparative advantage enjoyed by countries with low labor costs can be expected in other countries as microprocessor-based automation begins to take hold in the industrial world in the coming years.

It is important to keep the impact of microelectronics in perspective, however. The structure of the global economy will be more immediately and deeply affected by such developments as rising energy prices, changing demand for consumer products, protectionist import policies, and global inflation. But by constituting a new pole of potential growth and by changing the labor content of various production processes, microelectronics are going to play an important, if more subtle, role in shaping international economic relationships in the decades ahead.

Microprocessors and Political Processes

The development of microelectronics is coming to fruition at a time of sluggish economic growth and record postwar levels of unemployment in many Western industrial countries. It is this gloomy economic environment that makes the technology at once promising and threatening. On the one hand, it offers the prospect of enhanced productivity and the chance to revitalize some economic activities. But on the other hand, it threatens to aggravate unemployment in some industries and to reinforce the structural divisions that have been growing in the industrial countries during the past few years, as youth unemployment has climbed to epidemic levels and joblessness among blue-collar workers in heavy industries has risen sharply.

In many respects, the development and application of microelectronics brings into focus the issues that surround the so-called reindustrialization policies being pursued by several Western governments. At the heart of those policies is an attempt to boost productivity by stimulating high-technology industries that offer prospects for rapid growth and long-term economic success. Since the electronics industry is one of the leading growth areas in an otherwise flaccid global economy, it has naturally risen to the forefront of discussions of reindustrialization. The hope is that microelectronics will be able to overcome some of the constraints on productivity growth that have emerged in virtually every country in recent years.

In part, the attention being lavished on microelectronics—and the government funds being poured into its development—is a response to international economic pressures. In an interdependent world economy, governments have little choice but to ensure that their high-technology industries are in good health. As a 1978 paper by Britain's Labour Government put it, "as a trading nation we have only one realistic option—to seize the opportunity provided by this new technology to catch up with our industrial competitors and to adopt and develop it at least as fast and as comprehensively as they do. To opt out will lead to the very worst fears being realised." A report to the French Government put the matter a little more starkly: "France is being forced by the imperative of foreign trade to compete in a race over which it has no control."[82] If the implications are sobering for the advanced industrial countries, they are even more alarming for countries that have barely one foot on the industrial ladder. The microelectronic revolution adds a new factor to international competition that could make it more and more difficult for poor countries to close the technological gap.

There are two dimensions to the international race. The first is the competition to stay in the vanguard of the technology of constructing integrated circuits. In this race, the United States holds a commanding position, while Japan is rapidly moving to the forefront in some areas. European countries are currently lagging behind. The benefits of keeping abreast of the technology are in one sense obvious—there is a $10 billion global market in microelectronic devices—but there are also hidden advantages in the cross-fertilization between designers and users of microelectronics. More important, however, is the competition to use microelectronics in goods and industrial processes, for this is where the chief economic benefits lie. Those countries that move most rapidly in using the technology will gain a competitive advantage in international markets. Those that do not embrace the technology rapidly enough will see their position in world trade eroded. The experience of the American automobile industry in failing to adopt front-wheel-drive and other energy-saving technologies provides a painful reminder of how severe the economic penalties of technological backwardness can be.

These pressures, both political and commercial, make it inevitable that microelectronics will be developed and applied as swiftly as possible. But the efforts to push the technology have so far not been matched by policies to deal with its potential negative side effects. The nostalgic hope seems to be that microelectronics, along with other high-technology industries, will lead the way back to the golden days of the postwar era, when the world economy expanded at a rate that provided a high demand for goods and services and that in turn created millions of new jobs. Such a development is at best unlikely.

Virtually every recent study of world economic prospects has concluded that the global economy faces a period of slow and uncertain growth. The reasons are well-known: rising energy costs, concern over environmental degradation, the use of restrictive monetarist policies to dampen inflation, and growing protectionism in international markets. The development and application of microelectronics and other technologies will help to stimulate growth in some areas, but it will do little to remove the underlying causes of sluggish economic growth.

In the fifties and sixties, when there was a felicitous combination of rapid technological change, cheap energy, and unprecedented economic growth, the industrial countries were competing for a slice of a rapidly expanding world market. Now they are competing for a share of a much more constrained market. In short, this means that modernization of domestic industries will be essential to preserve their ability to compete in international markets, but it will not necessarily lead to a major expansion of overall market size. This has grim implications for global employment. But it also suggests that Luddite resistance to microelectronics will ultimately be counterproductive. for failure to adopt the new technology courts the risk of massive job losses as domestic industries decline.

It is easy to point to the advantages of raising productivity with new technologies, but if those advantages are won at the expense of displaced workers, the fruits of technological change will be bitter indeed. And, as already outlined, the pervasive nature of microelectronics, coupled with its potential for introducing labor-saving change in both blue-collar and white-collar industries, will heighten the problems of adjustment.

The transition to the electronic age will thus require policies designed to deal with technological unemployment in addition to those that support high-technology industries. Simply hoping that the unemployment problem will disappear in the white heat of technological revolution does not constitute a viable employment policy in a period of relatively slow growth and rapid technological change. Most of the needed programs—industrial retraining, the creation of jobs in depressed areas, support for community development, and labor-intensive programs such as energy conservation and the development of solar energy—are already the topic of intense debate. All these programs are needed to tackle the current high levels of unemployment, with or without the microelectronic revolution. But the special problems posed by the widespread use of microelectronics also call for some special responses.

First, there is a need for advance warning, consultation, and retraining of displaced workers when the new technologies are introduced. Whatever the ultimate benefits of microelectronics, it is clear that there will be serious upheavals in industries where jobs are automated and workers face redundancy. Already, bitter disputes have erupted in the printing industry over the introduction of computer technologies, and it is likely that similar battles will be fought in other

> "The transition to the electronic age will require policies to deal with technological unemployment in addition to those that support high-technology industries."

sectors. Such disputes may be inevitable when the demise of a skilled trade is at stake. But the difficulties are compounded when there is minimal advance warning, no consultation, and little provision for retraining.

In the past few years, trade union councils in several European countries have begun to negotiate technology agreements with employers' groups. These can provide useful guidelines for negotiations over the introduction of new technology into local plants. The first such formal agreement concerning computers was signed in May 1975 by the Norwegian Federation of Trade Unions and the Norwegian Employers' Federation. It requires that there be full consultation between management and unions before computer technologies are introduced, and that union representatives join in the planning of new computer systems. A more comprehensive proposal, put forward by the British Trades Union Council, calls for the participation of unions in the planning of new technologies, industrial retraining, and joint union-management teams to monitor the progress of new technologies. Greater industrial democracy is needed to ensure that microelectronic technology is not used in a way that degrades jobs and deskills workers.

Agreements in principle are all very well, but for workers who face the prospect of technological unemployment, retraining is essential. More concerted action by both governments and industry is needed. Even *Business Week* has chastised American industry for failing to recognize the importance of sponsoring retraining programs. "Managers of U.S. industry have begun to realize that robots will take over an increasing number of assembly lines in the coming decade. But they still think of this as a technological challenge. They have not yet come to grips with the problems of retraining and reemployment it will create," suggested an editorial in the magazine. It added: "U.S. industry cannot leave a retraining program of these dimensions to a public education system that is having trouble teaching simple English and elementary arithmetic."[83]

Finally, if the widespread use of microelectronics does usher in a period of "jobless growth," attention must be given to new ways to distribute the benefits of this growth. Increased productivity can mean higher profits and earnings for a few, or lighter workloads and higher living standards for many. The benefits from economic growth have traditionally trickled down through higher wages, expansion in the number of jobs, and the use of tax revenues to support unemployment benefits, pensions, and other social programs. The time may have come to consider how to share work in a high-productivity economy. Proposals to reduce the number of work hours, through a shortened workweek, longer vacations, sabbaticals, and similar steps, have been raised in negotiations by several European trade unions. A few American unions, which have long resisted such notions, have begun to follow suit. Industry groups have, however, generally opposed these proposals.

Microelectronic technology promises an array of benefits, and the electronic age is already well under way. As it progresses during the last two decades of the twentieth century, it will lead to improvements in productivity in factories and offices, changes in the way information is processed, stored, and communicated, and alterations in the content of many jobs. Like all major technological changes, the transition to microelectronics will raise difficult political issues, among which the impact on jobs and employment is the most prominent. A combination of revitalized employment policies, greater industrial democracy, and new ways of distributing both the hours of work and the fruits of technological change are essential if the benefits of the microelectronic revolution are to be equitably shared.

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COLIN NORMAN is a Senior Researcher with Worldwatch Institute and coauthor of *Running on Empty: The Future of the Automobile in an Oil-Short World* (W. W. Norton, November 1979). His research deals with the social and political issues connected with the choice and control of technology. Prior to joining Worldwatch, he was the Washington correspondent for *Nature*.