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ROBOTICS AND THE ECONOMY

A STAFF STUDY

PREPARED FOR THE USE OF THE

SUBCOMMITTEE ON MONETARY AND FISCAL POLICY

OF THE

JOINT ECONOMIC COMMITTEE

CONGRESS OF THE UNITED STATES

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LETTER OF TRANSMITTAL

Congress of the United States
JOINT ECONOMIC COMMITTEE
(CREATED PURSUANT TO SEC. 5(a) OF PUBLIC LAW 304, 79TH CONGRESS)
WASHINGTON, D.C. 20510

March 25, 1982

Hon. Henry S. Reuss
Chairman
Joint Economic Committee
Congress of the United States
Washington, D.C.

Dear Mr. Chairman:

I am pleased to transmit herewith a staff study prepared for the Joint Economic Committee entitled "Robotics and the Economy," prepared by Dr. Richard K. Vedder of the committee staff. Helpful comments were provided by Dr. James K. Galbraith, Mark Policinski and Marian Malashevich of the committee staff. The manuscript was typed by Doris Irwin, and research assistance was provided by Albert Guarnieri and Thomas Ulrich.

The staff study shows that robotics are expected to play an important role in the revitalization of America and most of the alleged negative dislocative effects of robotic development are exaggerated. It suggests that in the long run, industrial robots should lead to improved working conditions, higher real wages and the creation of more jobs. The study reflects the views of the author and not necessarily those of the committee or its staff.

Sincerely,

Roger W. Jepsen

Roger W. Jepsen
Chairman
Subcommittee on Monetary
and Fiscal Policy

FOREWORD

By Representative Clarence J. Brown

If America is to regain its economic supremacy it must embrace new forms of technology embodied in a growing capital stock. An important step in the revitalization of the American economy was provided in the Economic Recovery Tax Act of 1981, which I enthusiastically supported. That legislation and other aspects of the President's economic recovery program provide an environment in which new forms of technology such as industrial robots can be exploited to their fullest potential.

America is about ready to begin a Robotics Revolution, as this study suggests. I am particularly proud of the fact that my native State of Ohio is a leading area in the development of robotics in the United States. Cincinnati Milacron is one of the Nation's leading producers of robots, while the DeVilbis Co. of Toledo is also an emerging force in the industry. Also, my State has many industries -- steel and automobiles are just two examples -- where robotics are expected to have an important impact in coming years.

This study describes the functions and use of robots and describes the industry's explosive growth. It analyzes the impact that robots will have on employment opportunities, rejecting the view that the introduction of robots will destroy lots of jobs. To the contrary, the study suggests that robotics will provide us with a means to reverse our productivity slowdown and start growing again. With greater productivity growth, we can have increases both in real wages and employment, not to mention better working conditions associated with the elimination of human labor in many unsafe and undesirable tasks.

The study argues that job displacement from the introduction of robots is likely to be less than would occur if we failed to match the efforts of our overseas competitors in modernizing industrial capacity. Moreover, it suggests that in many cases there should be little or no direct job loss from introducing robots, but substantial indirect employment gains arising from new jobs being created in other sectors of the economy.

I share the generally optimistic view of this study, but also agree that we need to carefully study the employment effects of the Robotics Revolution so that we can redirect public policy to make it more responsive to the changes resulting from robotics. For example, it appears that we need to redirect and possibly expand our educational and vocational training efforts to provide the human capital necessary to handle new forms of employment that will replace old forms of blue collar skills. To encourage the expansion of robotic technology, we need to promote greater cooperation between research scientists in our universities and their counterparts in private enterprise, seeking to foster both a growth and more efficient use of our high technology infrastructure.

Robotics can be an important tool in the revitalization of the American economy. We must embrace the Robotic Revolution with its potential to improve the quality of life by creating new jobs and a higher standard of living. At the same time, we must respond to this Revolution in allocating our governmental resources, so that we can minimize the dislocative effects of robots and enhance our role as a world leader in this new form of technology.

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ROBOTICS AND THE ECONOMY

By Richard K. Vedder*

I. INTRODUCTION

Few technological developments of the last decade have as profound a potential impact on labor markets, working conditions, and the quality of life as the introduction of robots into the workplace. While the quantitative importance of robotics is still relatively small, continued technological advances coupled with an increasingly attractive investment and research and development climate (manifested in the historic 1981 tax cut) could lead to a Robotic Revolution that will have an important impact on the future American economy. And nowhere will this impact be greater than on the workers of this country.

It is unfortunate that public debate over robots has pitted the robot against the worker in a winner-take-all fight with the greater efficiency of the robot attempting to offset the human creativity of the worker. The advantage of one provides disadvantage to the other: Supposedly, in time, workers will have to accept lower wages or increased output to prevent the wholesale loss of jobs to an army of robots.

This report finds that this pessimistic viewpoint has little basis in fact. We reach this conclusion based on four factors. First, the estimate of the number of jobs that could be performed by robots by 1990 is definitely less than 10 percent of all jobs and probably less than 5 percent. Second, of these workers displaced by robots, almost all would be spared unemployment because of retrainment and retirement. Third, that total employment is a function of real economic growth and robots can have a positive effect on real economic growth and, therefore, a positive effect on total employment. Fourth,

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*Richard K. Vedder is an economist on the staff of the Joint Economic Committee.

that in ten years, retraining programs can adequately shift displaced workers to new careers. In fact, the challenge to policymakers due to increased use of robots is not unemployment but retraining.

The pessimist argument is that robotics will mean a major loss of jobs and with that the further stagnation of the industrial heartland of America. One pessimist, for example, has suggested that 100,000 jobs may be eliminated in the automobile industry alone.1/ One university study suggests that perhaps 1,000,000 jobs in factories could be eliminated by robots by 1990.2/ An implication of the pessimist view is that robotics will bring harm to some Americans and that therefore we must be careful in allowing the Robotic Revolution to proceed, certainly by establishing government policies to make the growth "orderly" and to ameliorate its harsher impacts. A proponent of a pessimist viewpoint might favor imposing mandatory "economic impact statements" for firms wishing to install robots, with some agency reviewing the statements before the robots could be installed. Similarly, laws might be passed requiring very large severance benefits for any person who can demonstrate that his or her unemployment was related to the introduction of a robot.

This pessimist view is somewhat reminiscent of the attitudes of the Luddites, bands of English workmen who organized to destroy machinery during the middle of the Industrial Revolution, believing that the machines that they destroyed had taken their jobs. History shows that labor saving

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1/ Harley Shaiken, "A Robot Is After Your Job," New York Times, September 3, 1980, p. A19.

2/ See "Robots Are Coming to Industry's Service," The Economist (London), August 29, 1981, p. 75. The specific estimate of the Carnegie Mellon University study is that by 1990 four to seven percent of factory jobs could be filled by robots.

techniques have led to improved living standards, higher real wages, and employment growth. In large measure, the Robotics Revolution is merely a continuation of a centuries long trend that has resulted in enormous material progress.

This study rejects the pessimist position. Rather, it finds the evidence overwhelming that robotics will raise productivity and with that the material rewards to employers and employees alike. New forms of employment can be created to offset any jobs directly lost to robots. Protection from job loss can come through retraining programs. Working conditions and job safety will improve as robots take over dangerous and undesirable forms of work. Because robots permit qualitative as well as quantitative improvements in goods and services produced, the vigorous introduction of robots will allow the Nation to maintain and expand vital export markets, while failure to introduce robotics will ultimately cause the loss of such markets. Moreover, states with a rich tradition of producing machine tools and other capital goods equipment can benefit directly from the growth in demand for robots, which will be built by human labor (perhaps aided by robots) and capital.

However, though public policy should implement tax policies aimed at encouraging capital formation and research and development, it should be neutral in the allocation of resources between robots and other forms of capital investment. Also, governments can assist by educating the public about the long-run positive aspects of the development of robotics, attempting to ease the fears of individuals and groups frightened about the impact of robots on their jobs and lives. Governments should promote the retraining of workers facing temporary unemployment in allocating its expenditures among alternative uses.

II. WHAT IS A ROBOT?

The first difficulty in chronicling the growth in the use of industrial robots in recent years is one of definition. What is an industrial robot and how do robots differ from other forms of labor-saving capital? One commonly used definition is provided by the Robot Institute of America (RIA), a trade association of robot manufacturers and users, which defines a robot as:3/

> a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices . . . through variable programmed motions for the performing of a variety of tasks.

A keyword in the definition is "reprogrammable," meaning that robots can be used without human operators to control the robot's motions and also can be adopted to new, different uses, for example, when changing styles force a change in materials or parts used. The word "manipulator" in the definition refers to the base and arm of the robot,which move the parts or other materials handled by the robot. The operation of the manipulator is governed by a second component of all robots, the controller. The controller might simply be a series of timers, stops or adjustable switches, but increasingly consists of computers and microprocessors. Thus the development of robotics is intimately related to the revolution in computer technology and especially to microprocessing devices. A third component of a typical robot is the gripper, a device that handles parts -- the counterpart to the human hand (grippers are sometimes called effectors or, more straightforwardly, hands). Grippers may be mechanical, magnetic, or vacuum devices.

3/ RIA News, Robotics Today, Spring 1980, p.7.

Robots can be driven or powered in at least three different fashions. Pneumatic drives using compressed air to move the gripper are relatively cheap (the whole robot seldom selling for more than $20,000) but they are comparatively weak. Electric motors, by contrast, are energy-efficient and are stronger, but are expensive (often more than $100,000 apiece). Somewhere in between both with regard to cost and strength are hydraulically driven robots using compressed fluids to move the arm.

Robots come in all sorts of shapes and sizes, although not typically in the human-like shapes portrayed in science fiction. Robots perform a diversity of tasks, with the variations likely to grow dramatically in the future as new uses are devised to utilize new capabilities. In particular, recent research has focused on giving robots a sense of visual perception. This form of perception is useful, for example, in allowing a robot to pick out the right part for a task in a bin containing many parts. Similarly, a sense of touch has similar advantages in giving robots greater diversity and allowing them to perform tasks which vary somewhat from operation to operation. Technological advances in computers and microprocessors are increasing the sophistication of robots, giving them some "thinking" capacity that increases potential uses.

III. THE USE OF ROBOTS

Robots have been primarily used in manufacturing. In the United States, a pioneer user was General Motors, which used them for welding at its Lordstown, Ohio plant where robots there led to a 20 percent production increase with slightly fewer workers.[4/] The auto industry remains a major user of robots, not only for such "heavy" or dangerous tasks as painting and welding, but even for such jobs as screwing light bulbs into instruments panels. The metal industries are also heavy users, e.g., in moving molten steel pieces through various processes. One-third to one-half of all shipments of robots have been to the automotive and primary or fabricated metals industries.

Of course, robots are useful in other manufacturing tasks as well. One of the most ambitious American conversions to robotic technology is being carried out by General Electric, which ultimately expects to replace half of its 37,000 appliance assembly workers with robots, hoping to have as many as 1,000 robots in place by 1990. Already robots are performing such tasks as spraying paint on refrigerators.

Potentially the Robotic Revolution's greatest impact may well come in the service industries where employment has been growing the fastest in the last several decades. The key to usage in such areas as office work depends in large part on the ability to develop "intelligent" robots capable of performing tasks that vary somewhat over time. Some industry observers believe breakthroughs may allow for extensive introduction of robotics in non-manufacturing tasks within a few years.

4/ "The New Industrial Revolution: How Microelectronics May Change the Workplace," The Futurist, February 1981.

Any "census" of the robot population is handicapped by a lack of a complete agreement on the definition of robot. The RIA estimated that more than 3,000 robots were in use in the United States two years ago; the Japanese claimed the use of 47,000 robots, but their definition of robots is considerably broader than the American one.[5/] Nonetheless, Japan probably had 14,000 robots using the American definition, more than the rest of the world combined, and approximately 10 times the per capita use of the United States. More recent estimates of the robotic population placed the number of individual robots in the United States at nearly 5,000, a sharp increase over the total of two years ago.[6/] Some small countries are moderately robot-intensive. For example, Sweden's 600 robots in 1979 amounted to 75 per million population, compared with a U.S. figure of perhaps 15 per million.

Estimates of the expected growth of the robot population vary widely, although virtually every student of the question expects significant growth in the Eighties and beyond. One very conservative estimate believes that annual robot shipments will exceed 2,500 a year by 1984 (nearly the total accumulated stock of robots as of two years ago).[7/] Another group (National

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5/ Robot Institute of America, Preliminary Results of Worldwide Survey, unpublished paper, 1979, p. 1.

6/ Joann S. Lublin, "As Robot Age Arrives, Labor Seeks Protection Against Loss of Work," New York Times, October 26, 1981, p. 1.

7/ International Resource Development, Inc., "Industrial Robots in the 1980's," Norwalk, Conn., November 1979, p. 25. See John Fisk, "Industrial Robots in the United States: Issues and Perspectives," Congressional Research Service Review, July-August 1981, for a good discussion of the growth of the industry.

Bureau of Standards and the RIA) are far more optimistic, expecting annual shipments to reach 4,800 a year by 1985 and 17,100 by 1990.[8/]

The Russians are making a major effort to catch up with the Americans and Japanese. The Soviet Union's current five-year plan calls for the construction of 40,000 robots, "more than the most optimistic projection for the combined output of America's robot builders."[9/] Russian robots are less sophisticated than American robots, most having neither electronic controls nor electrical motors.[10/]

The forecasted dollar value of shipments will soar, although will probably not reach momentous proportions compared to some other forms of capital goods spending. One firm has estimated that shipments by 1985 will be $438 million in 1979 dollars (perhaps $540 million in 1981 dollars).[11/] While sales estimates beyond 1985 are highly conjectural, one forecast places 1990 sales at $2.1 billion.[12/] This implies an extraordinary real sales growth of 34 percent a year over the next nine years, assuming 1981 sales are about $150 million as some have estimated.[13/] Growth in shipments depends in large part on the speed of improvements in robot capabilities, such as the introduction of effective and inexpensive sensory devices and, potentially more important, of capabilities permitting robots to do moderately intricate assembly work or tasks in the service industries.

7/ International Resource Development, Inc., "Industrial Robots in the 1980's," Norwalk, Conn., November 1979, p. 25. See John Fisk, "Industrial Robots in the United States: Issues and Perspectives," Congressional Research Service Review, July-August 1981, for a good discussion of the growth of the industry.

8/ U.S.National Bureau of Standards, "NBS/RIA Robotics Research Workshop," unpubl.

9/ "Russian Robots Run to Catch Up," Business Week, Aug.17,1981, p.120.

10/Ibid.

11/ Frost & Sullivan, The United States Industrial Robot Market (N.Y., 1979).

12/ Kathleen K. Wiegner, "The Dawn of Battle," Forbes, October 26, 1981, p.77.

13/ Ibid.

As Table 1 indicates, the growth in output is expected to be substantial in all areas where robots are used, with the possible exception of heavy machinery. Note the particularly dramatic growth in projected sales of robotics in the electronics and electrical machinery industries. The estimates in Table 1 are subject to substantial error, as a lot depends on the rate of technological advance. As one robotic pioneer, Joseph Engleberger, says, "When we get robots with vision and tactile feedback - and lots of people are working on it - then things will blossom."[14/]

In addition to developing a sense of sight and vision, other improvements are likely. For example, robots that can understand simple spoken commands are being developed. Also hand-to-hand coordination can make it possible to have robots with multiple arms. As improvements develop, new uses will be found for robots that even roboticists have not foreseen. Engleberger relates how Australians have attempted to adapt robots to sheep shearing, an agricultural use of robots no one predicted. The unpredictability of the speed of technical progress makes the previously cited forecasts very problematical. The preliminary evidence, however, is that they are probably an understatement of the speed of growth. For example, General Motors alone has talked of spending $1 billion or more by 1990 to install some 14,000 robots, nearly three times the current number in place in the entire American economy.[15/]

14/ As quoted in Fred Reed, "The Robots Are Coming, The Robots Are Coming," Next, May-June 1980, p.33.

15/ "Robots Are Coming to Industry's Service," The Economist (London), August 29, 1981, p. 71. There are many good survey articles on the growth of robotics. Two good ones include "The Robot Revolution," Time, December 8, 1980, pp. 72-83, and "Robots Join the Labor Force," Business Week, June 9, 1980, pp. 62-76.

Table 1

Estimated Industrial Expenditures on Robots, 1979-1985
(in millions of dollars)

Industry	1979	1985
Electrical machinery	$ 16.0	$164.0
Automotive	15.0	54.0
Fabricated Metals	16.0	67.0
Electronics	1.6	70.0
Heavy Machinery	12.0	13.0
Others	19.0	71.0
Total	$ 79.6	$439.0

SOURCE: Frost & Sullivan, Inc. as reported in John J. Obrzut, "Robots Swing Into the 'Arms' Race," Iron Age, July 21, 1980, p. 49.

A major question is to what extent American manufacturers will provide for the rapidly growing U.S. market. One major Swedish manufacturer that has a small share of the market currently, ASEA, is opening a plant near Milwaukee in 1982 to produce robots. The most significant competition, however, is expected to come from Japan, which heretofore has exported little of its output. According to Kanji Yonemoto, executive director of the Japan Industrial Robot Association, "While Japan exports only 3 percent of its robot production at present, by 1985 we expect that percentage will rise to 15 percent."[16/]

16/ "The Dawn of Battle," p. 79

IV. THE ECONOMICS OF THE ROBOTIC REVOLUTION

Three important dimensions of the growth of robotics are subject to economic analysis. The first is the determinants of the magnitude of the growth of the robotics industry. The second is the impact of robots on unemployment. The third is the impact that robots will have on wages, profits and prices. While none of the analysis can provide precise accurate forecasts of the long term impact of robotics, it can identify the key factors that will determine such impacts and offer insight into some reasonable scenarios to expect.

The Determinants of the Growth in Robotics

There are two reasons for the growth in the use of robots, one related primarily to supply and the second primarily to demand. Turning very briefly first to demand, robots can often do higher quality work than human workers, performing, for example, more consistent welds or paint jobs. Qualitative improvements will increase the reputation for reliability, increasing the quantity demanded at any price, thereby permitting both high equilibrium or market prices and greater total sales. From a supply perspective, this lowers the cost of getting a product of given quality by cutting down on inspection costs and the number of items rejected for shoddy workmanship.

The major supply side advantage of robots arises when the cost per unit of robot-produced output falls lower than unit production costs from traditional production techniques. In calculating costs, not only are the obvious direct per unit capital costs of robots included, but also maintenance charges, indirect labor support costs, depreciation, additional property tax liabilities, etc. Traditional production costs would include not only wage and salaries, but fringe benefits, supervisory labor costs, estimates of expenses associated with absenteeism, work stoppages, etc.

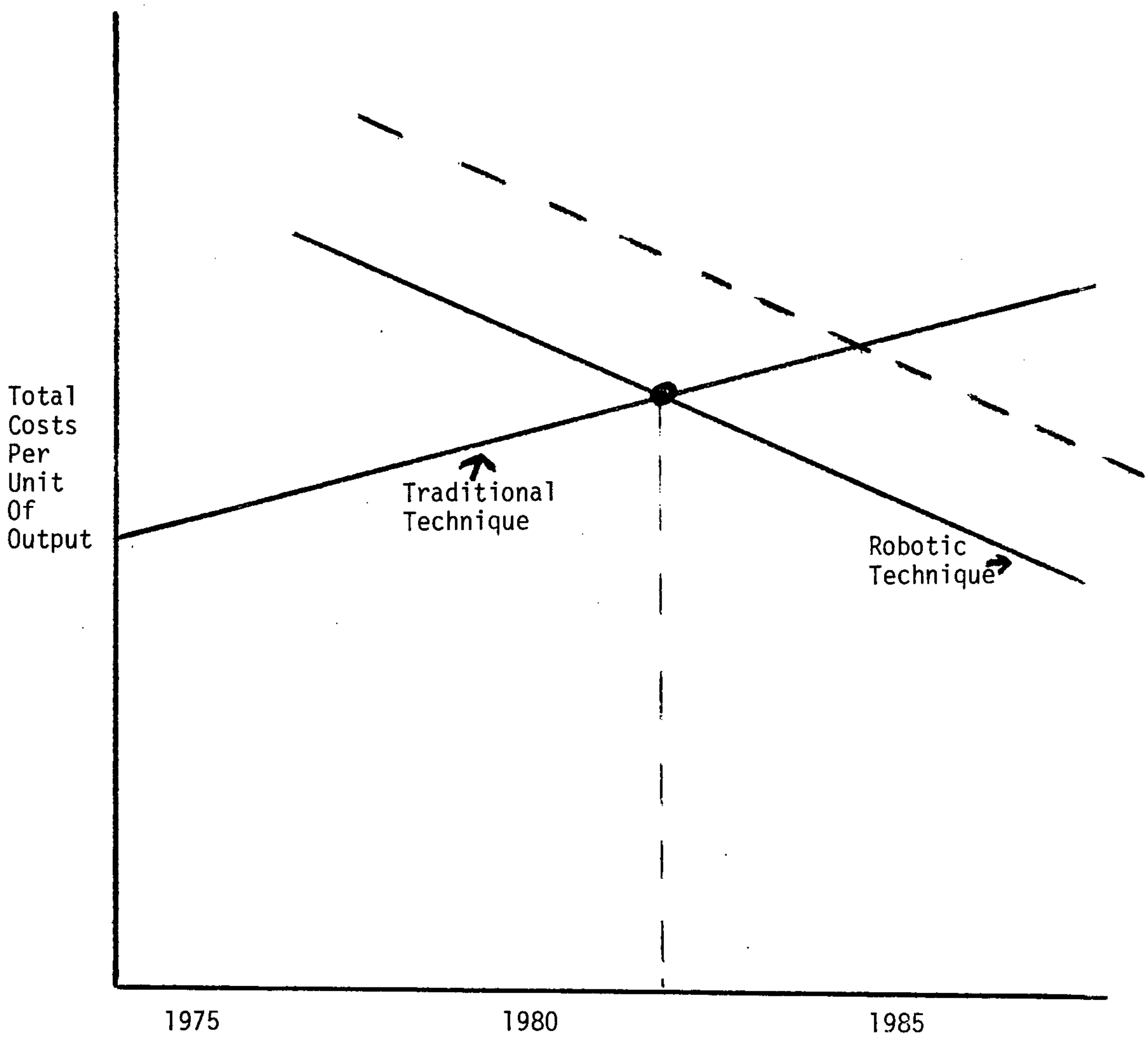
In the long run, robots are increasingly utilized because the cost of traditional labor-intensive techniques is rising over time, while the cost of the capital-intensive robotic techniques are falling relative to prices generally. These costs decline because the technological advances in robotics lowers the capital costs of robots per unit of output. This is illustrated in figure 1. In 1975, labor costs were significantly lower than they are today so it was much cheaper to, say, use a human welder than buy a robot costing perhaps $100,000. Assuming human wages continue to rise and the costs of robots continue to fall (relative to prices generally), by 1982 or 1983 the robot welder will become cheaper than human ones and the purchase of a robot will increase profits. Of course, this has already happened in many instances. Major potential users of robots are calculating the impact changes in labor costs will have on the decision to install robots. The Chairman of General Motors, Roger B. Smith, for example, recently stated that "Every time the cost of labor goes up $1 an hour, 1,000 more robots become economical."[17/] When the "threshold" to robots is reached will depend on the magnitudes of the changes in the relative price of robots and human labor. Public policies that raise the per unit cost of robots (e.g., by forcing firms to justify robots to a government agency by adoption, or by imposing high severance costs on employers displacing human workers) will shift the robot cost line upward (see dotted line), delaying the date at which robotics become profitable. Similarly, taxes or depreciation rules that lower the marginal rate of return on capital serve to retard the introduction of new techniques.

17/ John Holusha, "G.M. Shift: Outside Suppliers," New York Times, October 14, 1981, p. D1.

On the other hand, some government policies may speed robotic introduction. For example, where environmental regulations lower worker productivity or raise capital costs associated with traditional technology, the

Figure 1

Changing Per Unit Costs of Robots and Traditional Labor-Intensive Techniques



traditional technique cost line will shift upward, advancing the date at which robotic adoption becomes profitable. The actual threshold date will vary with the individual job involved, depending on wage levels of human labor, the capital cost of robots, the number of workers the robot displaces, the impact of robotics on product quality, the nature of union contracts, and other factors previously mentioned.

Employment Effects

The major argument against robotics is that jobs are destroyed. According to this view, individual workers are displaced by technology and must find new jobs or join the unemployment rolls. Analysis shows, however, that this concern is overstated or fails to distinguish between initial and secondary employment effects of automation, of which robotics is merely one form. Moreover, it presupposes the absence of vigorous retraining programs.

Though it seems logical that the initial impact of the installation of robots is to reduce employment and, sometimes, to create some unemployment, this has not been the case to any great extent. The purpose of the introduction of robots is to improve productivity, thereby enhancing the competitiveness of the firm and the welfare of individuals associated with it. The existence and size of the initial employment effects are often overstated, since the reduction in workforce resulting from the introduction of robots is partly offset by the hiring of maintenance personnel, workers to manufacture robots, and computer programmers to provide instructions to robots.

It should be noted that the structure of employment will change in what most persons would regard as a positive direction. Robots will usually replace workers engaged in monotonous tasks that are often physically overly demanding and mentally unrewarding. Sometimes, too, the jobs taken over by robots are dangerous for humans. Thus some displaced workers ultimately welcome robots as a means of freeing them to do more rewarding tasks. As one ex-painter who moved to an assemblyline job at General Electric after being replaced by a robot said, "At first I was bitter . . . but I didn't like breathing the paint. The robot may be saving my life."[18] Similar reasoning probably explains why in Sweden "the trade unions have actually demanded the installation of more robots, because they do the jobs the workers don't want to do, and they do them right."[19]

The new jobs created by robotics are typically skilled jobs that are mentally challenging, physically non-tiring, and safe. Moreover, there are important secondary employment effects of the introduction of automated equipment. The "supply side" changes resulting from the introduction of robots should induce "demand side" changes which will stimulate employment. Moreover, these same changes should lead to improved material living standards for all employers through their impact on wages, profits and prices. How does this result?

Robots raise productivity of the remaining workers. This can be illustrated with a hypothetical example. Suppose a widget factory could increase its output by two units a day by adding one more worker. If widgets sell for $30, an additional worker added to the production line would increase the firm's revenues by $60. Now, suppose robots are introduced and one additional worker, a robot-fixer, could oversee maintenance on two or three

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18/ "As Robot Age Arrives . . ., p. 21.

19/ Bengt Johanssen, as quoted by Thomas W. Lippman, "The Reprogrammable, Multifunctional 'Man'," Washington Post, October 16, 1981. p. D9.

robots, capable of adding five widgets daily to output. The "marginal productivity" (additional output) of another worker increased from two to five widgets a day; at $30 per widget, the value of a worker's marginal product increased from $60 to $150. It becomes more profitable to hire workers at any given wage. Previously, the firm would not pay any worker more than $60, since to do so would be unprofitable. Now, however, the firm can pay up to $150 and still add to its profits by hiring the robot-fixer. The firm, of course, would like to pay the worker much less than $150, but competition for skilled robot-fixers will force the wage that it has to pay up to near the $150 figure.

Now, in the real world the improvement in wages associated with the introduction of robots is not likely to be as dramatic as the example illustrates, for several reasons. One of the major reasons is that the increased willingness of firms to supply output (widgets in this case) because of declining production costs associated with higher worker productivity will force firms to cut prices in order to sell goods. Suppose widget prices fall by 50 percent, to $15. The value of the marginal product of workers will go from $60 before the introduction of robots to $75 (5 units at $15 each). This sets the stage for a wage increase of $15. The lower price of widgets, however, will mean that other consumers far removed from the widget industry will also benefit. Their real income will increase, as they can buy more goods (at least more widgets) from their paycheck. Similarly, the owners of the widget factory will introduce the robots only if the total cost per unit of output (after allowing for higher wages for the remaining workers) declines enough so that the expected profit is increased. Whether this actually happens, of course, depends on the accuracy of the owners' perceptions of the widget markets, the price effects of increased output, the degree of productivity gain associated with robots, etc. If things go as expected, everyone should gain through the adoption of the new innovation, a robot: workers in the form of higher wages, consumers in the form of lower prices, and the producer in the form of higher profits.

But what about the workers who lost their jobs because of the robots? To begin with, it should be mentioned that generally the introduction of robots does not involve any direct unemployment, as robots are introduced gradually and, in effect, replace workers who are retiring or quitting. One survey of users and manufacturers of robots suggests that about 95 percent of the jobs displaced by robots between now and 1990 will not involve unemployment, as workers will be retrained or, in some cases, be of retirement age.[20/]

Yet there is no denying that without prior retraining vigorous introduction of robots in some instances could create unemployment. However, the higher wages of remaining workers, high real incomes to consumers from lower prices and higher profits for producers will enhance the demand for goods, since consumption and investment spending is directly related to income. Greater investment also will ultimately assist in economic growth by increasing productive capacity. Say's Law is at work, which, crudely put, says that supply creates its own demand. This leads to employment demand increases in other sectors, which will allow the unemployed to be absorbed into the labor force.[21/]

20/ "As Robot Age Arrives . . .", p. 21.

21/ Not all classical economists agreed with Say that supply changes would create adequate demand. David Ricardo disagreed as it pertained to technical progress. See David Ricardo, On the Principles of Political Economy and Taxation (Harmandsworth, England: Penguin Books, 1971). Ricardo believed, however, that technical progress worked to the benefit of the workingmen, raising wages for them.

Even economists who find little validity in Say's Law would agree that it is possible to offset the unemployment creating effects of robotic unemployment. The orthodox (Keynesian) view is that monetary and fiscal stimulus can provide the level of demand necessary to provide jobs for unemployed workers. Thus both "liberal" and "conservative" economists would reject the view that the widespread introduction of robots needs to create unemployment, even though they might differ on the precise policy prescription desirable to deal with the issue.

In summary, it would be difficult to improve on the assessment of the Economist of London:22/

> Most of the skilled workers doing some of the 4-7% of American jobs that could be taken over by robots by 1990 should welcome their incursion. Robots will have to be taught to do their jobs and be supervised while they work. American companies are discovering that few people can teach or supervise a robot better than the men who did the job before. Although fewer people are needed in the trade as a whole (thus cutting the clout of union officials organizing that trade), the skilled people in the factories where robots are welcomed generally get more interesting jobs at higher wages. Joblessness is created in the firms that fail to welcome robots.

While the Robot Age will not mean massive unemployment for workers, it will have important implications for the training of workers. One follower of the industry, Eli S. Lustgarten of Paine Webber Mitchell Hutchins,Inc., puts it well:23/

> Retraining is the major social problem created by rapid robotization, not unemployment. The jobs created by widespread use of robots and unmanned manufacturing -- programmers, technicians, engineers -- for the most part require a high degree of technical training. Massive training programs will be needed to prevent the creation of an oversupply of workers whose skills have become obsolete and simultaneous shortages of engineers and technicians.

Much of the needed retraining probably will be provided in collective bargaining agreements. There are indications that some unions are pushing for

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22/ "Robots Are Coming . . .", p. 75.

23/ "The Reprogrammable, Multifunctional 'Man'," p. D10.

such retraining programs. This approach is far more desirous from the standpoint of workers and the whole economy than the alternative approach of trying to prohibit or limit the introduction of robots. Extensive adoption of retraining clauses in labor contracts will also alleviate the need for governmental responses. It should be pointed out that changing job requirements associated with previous automation have led to market-induced responses from workers. For example, the increased demand for engineers will lead to a rise in engineering school enrollments as prospective engineers are lured by a market signal in the form of higher salaries. Market adjustments, while not instantaneous or perfect, usually will resolve the problem eventually. Private retraining programs, however, will ease the adjustment.

Government can aid market adjustments by disseminating labor market information and by modifying or expanding existing public vocational education programs to meet the changing requirements of industry. It almost certainly will become desirable to reallocate public expenditures towards educational programs that produce skills compatible with labor markets in the robotic era.

Assistance for job retraining may take several forms. Direct assistance for educational retraining may be given to individual workers threatened with job loss. One possibility is to give workers "vouchers" that will pay retraining expenses at either private or public institutions. Direct assistance to public vocational institutions probably will have to be increased. Since many of the jobs created by robotic technology will require sophisticated advanced training, universities can be expected to play a major role in the retraining of workers. Institutions of higher learning will not only be important for their dissemination of knowledge about robotic-related skills, but also in the creation of new technology designed to further advance the introduction of robotics into the workplace.

The alternative to a positive policy towards the introduction of robotics reflected in job retraining programs would be to adopt policies designed to discourage the introduction of robots. For example, suppose that the citizens of Ohio, working through the political process in that State, decided to do something to discourage robots, hoping to prevent unemployment in such potentially robot-intensive industrial centers as Cleveland or Youngstown. Perhaps a special robot tax of $10,000 per robot would be imposed, collected annually. Alternatively, subsidies for non-robot technology might be granted. Would it help the workers of Ohio? Emphatically no. Instead of job losses to Ohio robots, the job losses would be to workers (and robots) in other States and countries which reject policies designed to impede productivity growth. Productivity of Ohio firms would decline relative to firms in Illinois, Michigan, Japan or Germany, making Ohio companies less competitive. This would lead to a decline in sales and/or profits, and ultimately in rising unemployment as Ohio firms lay off workers. As long as there is some place in the world where there are no impediments to the introduction of the new technology, any attempt to restrict the ultimate adoption of the technology will prove self-defeating, with unemployment and negative income effects from a loss of business to outside companies greater than if a pro-robotic (or at least a neutral) public policy were followed.

V. LOCATIONAL EFFECTS OF ROBOTIC INTRODUCTION

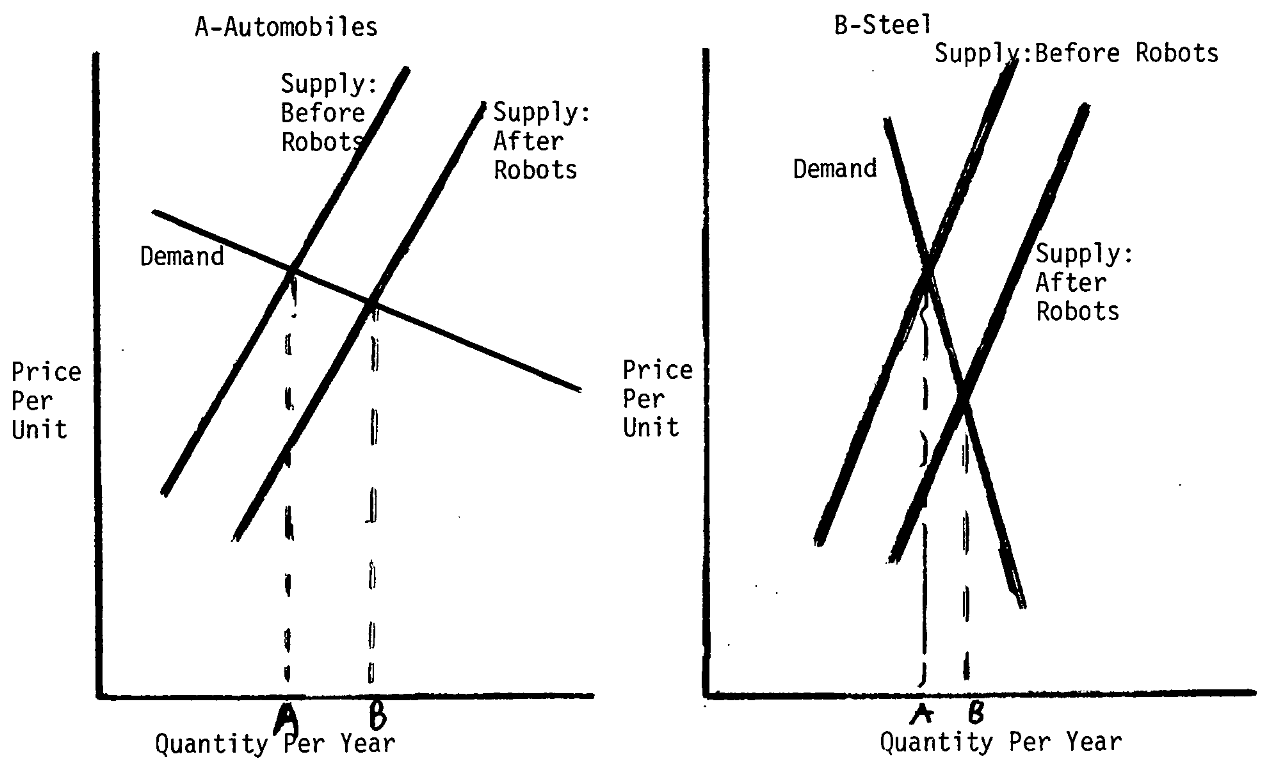
Robots are not likely to be evenly distributed geographically over the economy and it is therefore true that the initial and possibly even the ultimate impact of robotics will vary somewhat from region to region. States like Ohio and Michigan, with robotic-intensive industries like steel and automobiles, will be impacted more than states like Nevada or Vermont. Won't robots hurt these localized economies in the Northeast and Midwest even though the Nation as a whole gains? The answer, emphatically, is "no".

The cost-reducing dimensions of the introduction of robots may well lead to increases of output in the robot-using industry that will offset the employment impact of robotics. Indeed, it is very possible that robot-usage will stimulate total employment in the industry introducing the robots (even though, paradoxically, the industry is replacing workers with robots). The exact employment impact depends on several factors directly influencing the sensitivity or elasticity of demand and supply for workers and the elasticity of demand for the final product. To simplify a potentially highly complex and technical analysis, let us just consider the final point, the elasticity of demand for the final product.

Suppose robots are introduced into an automobile plant where a car is produced for which customer acceptance is highly dependent on price, and also into a steel plant which produces a specialty steel for which sales are not highly sensitive to price. Pictorially, graph A of figure 2 suggests a small change in price would induce a fairly large change in the quantity demanded for autos, while in graph B the output effects are smaller. Introduction of robotics lowers production costs and increases the quantity of product that firms are willing to supply at any given price, moving the supply curve to the right.

Figure 2

Demand Effects of the Introduction of Robots



In the auto industry (graph A), the demand and supply curves intersect at a new market ("equilibrium") quantity that is much greater than before (point B rather than point A), while in the steel example (graph B), the increase in output is much smaller. In the case of autos, then, the loss in employment resulting from greater output of cars per worker after the introduction of robots is offset by a sharply higher output of cars. Total employment may indeed rise. In the steel example, however, the output effects are not as stimulative to employment. Thus the employment effects will vary with the elasticity or sensitivity of demand to changes in prices.

It is quite feasible, however, for robots to have a favorable impact on employment as depicted in graph A, as highly inelastic demand is the exception rather than the rule for products of American industry. Even in the steel case, however, the secondary employment effects are profound. Note in graph B that the price of steel falls significantly. Since steel is used in other products, the cost of producing those products will decline, increasing the supply and output of those products, thus likely increasing employment in those industries. Thus the secondary spillover effects should have very positive employment effects outside the industry in question.

Some areas will enjoy some direct employment gains from the manufacture or maintenance of robots. This impact will not likely be dramatic, however. Even if the most optimistic forecasts of sales growth materialize, total employment in robotic manufacture would not exceed 50,000 at any time in the next decade.

VI. SOME HISTORICAL EVIDENCE

Robots are fairly new and even in Japan their use to date has not been of a magnitude that would have far-reaching effects. Therefore, it is very difficult to assess the future economic impact of robots on the basis of the very limited past experience. While robots are clearly an "ultimate" form of machinery, they really do not differ economically in their impact from other forms of machinery which have substituted or replaced labor in the past. Robots are another form of "automation" or "mechanization." There is ample historical evidence that automation in the past has led to greater employment, and sometimes even to greater direct employment in the industry where automation occurs.

The best historical example perhaps is what in a sense is the first example, namely the cotton textile industry during Britain's Industrial Revolution. The very era when the Luddites were destroying machines to save jobs saw automation far greater in its employment displacement effects than the robots of today are likely to cause. By 1812,"one spinner could produce as much in a given time as 200 could have produced before the invention of Hargreaves' jenny" (patented in 1770.)[24/] But what happened to employment in the cotton textile industry? It increased considerably, from probably less than 100,000 in 1770 to about 350,000 in 1800. The increase in supply in large part resulting from a form of highly labor-saving mechanization, coupled with an elastic demand for output (both with respect to incomes and price), led to such huge increases in output demand that employment rose. When one adds the secondary and tertiary employment effects (including cotton cultivation in the U.S. South), the impact

24/ Phyllis Deane, The First Industrial Revolution (Cambridge, England: Cambridge University Press, 1979), pp. 90-91.

was even more positive. The British lead in mechanization gave it a productivity edge that made that nation the most prosperous and powerful country during most of the Nineteenth Century, an era when literacy became widespread, the death rate fell as sanitary conditions improved, new cultural opportunities began and new material goods became available. One can even argue that England's Golden Age was a direct consequence of its leadership in developing the predecessors of today's robots.

Moving closer in both time and location, the greatest Twentieth Century example of automation in the United States probably is the introduction of the assemblyline and mass production into the automobile industry; Henry Ford's assemblyline evolved over a few years right before World War I. It was a dramatically successful attempt to organize men and machinery in such a way as to sharply improve productivity and reduce per unit labor costs. Did machines displace workers? Quite the opposite. True, it took 56 percent fewer hours of production workers to make an average car in 1920 than in 1910, and labor productivity rose an astonishing 8.5 percent a year.[25/] These production economies permitted the industry to cut the average price of cars by more than 62 percent in real terms. As a result, sales increased more than 10 times, leading employment of "operatives and laborers" to grow from 37,000 to 206,000 in just ten years.[26/]

In this connection, it is interesting to note that the industries where robots are having the most intensive application had extensive employment losses in the decade before robotics became extensively used. From 1967 to 1977 employment in the "primary metal" two-digit standard industrial classification

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25/ Derived from statistics in U.S. Department of Commerce, Historical Statistics of the United States, Colonial Times to 1970 (Washington, D.C.: Government Printing Office, 1975).
26/ Ibid.

declined by more than 167,000, while more than 65,000 jobs were lost in the "transportation equipment" SIC classification. It is noteworthy that primary metals, which lost more jobs than any other two-digit SIC classification, had increases in labor productivity well below that for manufacturing generally. Both classifications involve industries (e.g., autos, steel) which have lost markets to the Japanese and other producers which because of faster productivity advances have been able to sell their goods at lower costs than American producers. Reiterating a point made earlier, failure to adopt productivity-enhancing technology such as robotics will not prevent the continuation of the employment decline in these industries and probably would serve to accelerate it.

Research done by the Machinery and Allied Products Institute demonstrates that firms in the so-called "high technology" industries have consistently outperformed other enterprises in terms of employment growth. From 1955 to 1976, employment rose 20.7 percent in five high technology SIC classifications, compared with 7.1 percent for other classifications. At the same time, real output per worker (as measured by value added) rose in every one of the high technology industries faster than for manufacturing as a whole.[27/] Robots are certainly a form of high technology designed to raise labor productivity, so the evidence is highly consistent with the view that, on balance, robots will create more jobs than they will destroy.

Other evidence is consistent with the view that labor productivity such as that arising from the introduction of robots is more likely to have a positive rather than a negative effect on labor markets. There is evidence that

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27/ Machinery and Allied Products Institute, Memorandum, August 4, 1978, "Economic Performance of High Technology Industries," especially pp. 5, 23, and 24.

the United States unemployment rate varies inversely with productivity growth, and that the two factors are causally related.[28/] It is no accident that the well known productivity slowdown in the United States since 1973 coincides with the highest average unemployment rate witnessed since the Great Depression (see Table 2). Note that from 1973 to 1980, labor productivity rose very little compared with the period immediately preceding, while unemployment in the more recent period was much higher. There is also little doubt that real wages are very highly correlated with labor productivity (see Table 3). The recent productivity decline has had the impact of reducing real wage growth. Since workers receive well over three-fourths of the national income, the only way for them to have substantial long-run growth in their income is for the national output and income to expand through economic growth, which in turn depends on productivity advance.

Robotics consequently will have a positive impact on wage levels and will probably tend to reduce rather than increase unemployment in the long run. Moreover, the adoption of robotics will assist in meeting another urgent goal: price stability. The growth in output in recent years has been inadequate in relation to the growth in the stock of money, so prices have risen. As Table 4 indicates, inflation is greatest during periods of slow productivity growth, as "too much money is chasing too few goods." The solution to the problem is not only to reduce the growth in the stock of money but also to increase the output of goods by stimulating productivity by introducing such productivity-enhancing capital goods as robotics.

Evidence compiled by John Kendrick and others has suggested that technological progress and innovation have been the most important factors in explaining productivity growth. For example, Kendrick estimates that over one-

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28/ See, for example, Lowell E. Gallaway and Richard K. Vedder, "Money Wage Rate Adjustment and Asymptotic Rational Expectations," unpublished paper, Department of Economics, Ohio University, 1981.

Table 2

U.S. LABOR PRODUCTIVITY AND UNEMPLOYMENT, 1965-1980

Period	Annual Labor Productivity Growth	Mean Annual Unemployment Rate
1965-73	2.5%	4.45%
1973-80	0.6	6.88

SOURCE: Joint Economic Committee, 1981 Midyear Report; author's calculations from Department of Labor data.

Table 3

U.S. LABOR PRODUCTIVITY AND REAL WAGES, 1950-1980

Period	Annual Labor Productivity Growth	Annual Real Wage Growth*
1950-65	3.1%	2.5%
1965-73	2.5	2.2
1973-80	0.6	0.5

*Real compensation per hour, nonfarm business sector.

SOURCE: Joint Economic Committee, 1981 Midyear Report; 1981 Economic Report of the President; author's calculations.

Table 4

U.S. LABOR PRODUCTIVITY AND INFLATION, 1950-1980

Period	Annual Labor Productivity Growth	Annual Price Increase*
1950-65	3.1%	2.1%
1965-73	2.5	3.8
1973-80	0.6	7.0

*Nonfarm business sector price deflator.

SOURCE: Joint Economic Committee, 1981 Midyear Report; author's calculations from Department of Commerce data.

fourth of the productivity growth (small as it was) between 1973 and 1978 was attributable to formal research and development programs alone.[29/] Thus the improvement in robotics resulting from further research and development should contribute in an important fashion to reducing and reversing the U.S. productivity slowdown, assuming the growth is not stifled by inappropriate public policy.[30/]

29/ "Productivity Trends and the Recent Slowdown: Historical Perspective, Causal Factors, and Policy Options," in William Fellner, ed., Contemporary Economic Problems 1979 (Washington, D.C.: American Enterprise Institute, 1979), p.33.

30/ For a good analysis of the productivity slowdown and some possible remedies, see the 1981 Midyear Report of the Joint Economic Committee of the U.S. Congress.

VII. POLICY IMPLICATIONS

The empirical evidence clearly is that breakthroughs in labor-saving technology have stimulated output, wages and employment and have tended to reduce inflationary pressures. Most important, improvements in productivity accelerate the long run rate of economic growth for the material benefit of all. In the case of robotics, a useful secondary benefit is that robots can remove much of the danger and monotony of industrial employment while at the same time enhancing the quality of goods that consumers use.

Public policy, then, should not be hostile towards the development of robotics in the United States. Clearly, laws or regulations that in any way forestall or prevent the spread of robots are totally inappropriate. Beyond that, policies that tend to discourage capital investment in robots or research and development that will permit further technological advances are also inappropriate. Clearly U.S. tax laws have been overtly hostile to capital formation, with their double or even triple taxation (at high marginal rates) of returns to productive resources and the inadequate provision for depreciation of capital. The historic 1981 tax reforms go a long way towards improving that situation, although further improvements in the savings and investment climate (e.g., through more generous tax breaks for private savings) would be useful. In this regard, State and local governments must review their tax policies in light of increasing evidence that high taxes on productive resources at the State and local level can slow the rate of economic growth.

Although robots are relatively pollution free and actually reduce occupational health and safety hazards, heavy-handed government regulation could deter development, if by no other means than by "crowding out" investment in robotics. Therefore such seemingly unrelated matters as regulatory reform are relevent to the future of robotics.

While it would be socially undesirable to retard the development of robotics by taxes, regulations or prohibitions on their use, it probably would also be undesirable to further robotic development by artificial government stimuli, such as special subsidies for robotic use. Firms should be induced to use robots on the basis of real social savings as reflected in market prices, not because of government bribes that do not reflect true social costs or benefits. In short, the governmental authorities should be relatively neutral in the development of robotics relative to other technologies. Market forces will see to it that robotics are introduced on a large scale.

Does this mean there is no role for government in the Robotics Revolution? No. The Government can play a very important role in developing information that would provide an environment in which affected groups react to robotics objectively and on the basis of facts rather than on the basis of emotional, inaccurate claims that create negative attitudes which are potentially harmful. People need to be taught that the robot is their friend, not their enemy.

This brings us to the political economy of robotics. While the overall benefits of robots are likely to be real and substantial, a relatively small number of persons may be displaced by the introduction of robotics, at least in the short run. As the Economist quote cited earlier indicates, robots do have the potential of replacing blue collar workers who belong to unions with white collar workers (e.g., programmers of robots) who may not typically belong to unions. Thus robotization may come to be viewed by union leadership as "union-busting."

Governments (including State and local ones) should promote the dissemination of information on the advantages of the productivity advances in robotics and on means of minimizing or even eliminating their possible adverse impact. Perhaps States should form special Councils on Robotics to provide a forum for such information dissemination. In their own resource allocations, States as well as the Federal Government may wish to stimulate research and development efforts not only into improving robot technology, but also enhancing research into the amelioration of the economic and social impact of robots. Universities should be encouraged to study and enhance the Robotics Revolution. They, and other training institutions, should be assisted in expanding educational programs likely to impart skills needed for jobs created by the introduction of robots. Similarly, governments should ease labor market adjustments through dissemination of labor market information.

To break down hostility, Government leaders should further more informal gatherings of management and labor (e.g., in local labor-management labor relation groups) that explore the long-term implications of the impact of robotics outside the crisis-adversarial environment that surrounds collective bargaining negotiations. In such a non-crisis setting, attitudes towards robotics should be more open and trusting. White House Conferences on Productivity would be another forum for rational discussion of robots and their impact. Government can help make American management less aloof and more communicative with workers who have valid concerns, and at the same time make union members (and hopefully their leaders) more conscious of the mutual gains possible from the introduction of robots. In this regard, much can be learned from the Japanese experience.

Collective bargaining agreements that accept robotization in a positive fashion (by providing for retraining of displaced workers) rather than negatively (by attempting to block the introduction of robots) will probably serve the objectives of employers and employees alike. Government training programs should be focused to provide skills needed in robotics-related jobs.

The Robotics Revolution is beginning and those who fully participate will reap gains while those who shrink from participation will suffer losses in incomes and jobs. Market forces will provide the inducements or signals necessary to bring about the resource allocations needed, but Government can help by providing a positive tax environment that permits investors and workers a good return on their investments in human and physical capital. It can and should reduce regulations that hurt productivity and have little discernible offsetting social benefit. It can further support research and development spending on robotics and its effects. It can encourage retraining programs. It can play a leadership role in reducing the human concerns over robotics that potentially can block adoption. In short, the governments of the United States can help convince us that the robot is an important new friend.

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