Technological Change in Agriculture

The sources, diffusion, and social imports of technological change in agriculture are examined.

Richard E. Just, Andrew Schmitz, David Zilberman

Farming methods in the United States and other parts of the world are continuously changing. Public institutions and private corporations invest billions of dollars yearly in new agricultural techniques. The rates of return on these investments are much above the average for the economy as a whole (15 to 50 percent) (*1*). Yet, there is objection to the introduction of each new technique (especially a labor-displacing one), particularly by its potential victims. Not everyone agrees with the advertisement that "our business is manufacturing machines so that man can do more."

In this article we view some of the controversial issues concerning technological change in agriculture from the perspective of economic theory. We first explain the direction and nature of the process of technological change and then discuss the short- and long-run effects. The arguments for and against technological change and growth are critically evaluated.

Forms of Technological Change

Technological change involves generating useful knowledge pertaining to the art of production. More specifically, it involves a shift in the production function (which relates the quantity of outputs to the quantity of inputs) enabling greater output quantity or quality, or both, to be produced with the same volume of land, labor, and capital or the same output quantity and quality to be produced with less of at least one of the inputs. Often these shifts include changes in the quality of inputs, such as improved forms of machinery or more highly educated labor.

R. E. Just and A. Schmitz are professors and D. Zilberman is assistant professor of Agricultural and Resource Economics, University of California, Berkeley 94720.

Some broad classifications of the forms of technological change are biological-chemical, agronomical, and mechanical. Biological-chemical change is generally land-using and laborsaving. Agronomical change is generally land-saving, whereas mechanical change is usually laborsaving. Another classification has to do with whether technology is primarily yield-increasing or labor-saving. Many forms of technological change are complementary, and several forms often occur simultaneously. For example, implementation of the mechanical tomato harvester (a mechanical change that is laborsaving) gave rise to the need for, and was delayed by the lack of, a tomato variety (a biological change) suitable for mechanical harvesting. This case demonstrates that the type of technology likely to develop is a result of economic needs and incentives.

Process of Technological Change

A useful theory of technological change is that of induced innovation. Technological change is directed toward saving the progressively scarce or more expensive factors, that is, saving proportionally more of the scarce factor than of the abundant factor per unit of output at constant prices. More generally, the theory of induced innovation also considers the impact of final demand. Some tests of this theory are described by Binswanger and Ruttan (*2*). On the basis of this theory, Hayami and Ruttan demonstrated that, since land was relatively scarce in Japan, technology was developed to increase the productivity of land (*3*). In the United States, on the other hand, a considerable amount of technological development was directed toward increasing the productivity of labor in part because of the relative abundance of farmland and the scarcity of farm labor. Each of these processes of technological change had different effects on income distribution, general working and living conditions, and the structure of rural communities generally.

Another behavioristic pattern common to all economic agents and farmers in particular is aversion to risk. Farmers prefer to reduce uncertainty regarding their crop yields and future costs; as a result, they tend to replace inputs associated with uncertainty with inputs that promise more stable profits. Thus, for example, the tendency to replace labor with capital (during periods of unstable labor supply and threats of labor union strikes) can be explained by farmers' preferences for the predictable. Also, it appears that overcapitalization in farming is a rational, risk-reducing response to uncertainty in the weather because certain critical operations can be completed rapidly and thus reduce the farmers' weather vulnerability (*4*).

New technologies developed in response to these various economic incentives result from three sources: farmers, private corporations (for example, machine manufacturers, seed breeders, chemical companies), and public research institutions. In the case of farm producers, productivity is improved not only through purchase of improved physical inputs from agricultural input manufacturers but also through learning by doing (for example, improved knowledge of seeding depth and timing on a particular farm by trial and error)—an important farmer-generated form of agronomical technical change. However, farmers are generally limited in the extent to which they can develop agronomical technology since the cost of development, other than that of learning by doing, is too burdensome. As a result, farmers are dependent on those machines and seed varieties offered by large agribusinesses.

Private technology suppliers, in contrast, tend to develop and support only those technologies for which they can capture a substantial part of the benefits. Thus, private concerns tend to focus on mechanical and chemical developments that lead to patented products. Similarly, private concerns may strongly support other biological-technical change since the gains to machine manufacturers, fertilizer companies, and seed companies associated with increased production may be substantial. Apparently, this was the case with the Green Revolution. On the other hand, private enterprises are understandably reluctant to incur large expenses in developing technologies for which the benefits cannot be sufficiently

0036-8075/79/1214-1277$01.00/0

captured by the developing enterprise. The results of public research and development activities are likely to be diffused more rapidly than the results of private research since these new technologies become public information and are thus widely accessible at lower cost. Private research, in contrast, results in monopolistic control of information during the period of patent rights. This is also the case when technology is developed publicly and patent rights are sold, say, from a university to a private concern for marketing. A related issue that must be considered in conjunction with public research is that, because of the public nature of the results, private concerns are often able to reap the associated short-run benefits. Whether or not various individual groups of producers and consumers gain or lose in each case depends upon the type of technological development, as well as the market structure (degree of competition), factor mobility, the relationship of public and private concerns, and the like.

Income Distribution: Immediate Effects

In general, the adoption of any technology results in an increase in the supply of the product being produced (if there were no economic potential, the technology would not be adopted) (*5*). If a group of innovating producers makes up a large part of the market, competition will lead to lower product prices because of increased supply; hence, consumers will be better off. Benefits will accrue to consumers roughly in proportion to their expenditures on the product in question, and this partly depends on the distribution of income among consumers. For example, improved technologies in staples should benefit the poor relatively more than the wealthy, whereas improved livestock technologies may be relatively more beneficial for middle- and upper-income classes. Also, in the case of commodities that are exported where changes in domestic technology have minor impacts on world prices, producers capture relatively more of the gains.

The fact that different technologies lead to different input uses and productivities suggests that significant income distributional effects may also be experienced among factor suppliers. For example, consider the adoption of mechanical harvesting technology for tomatoes and cotton. An immediate effect of these developments was the displacement of harvesting labor by harvesting machinery which resulted in a decline in the total wage bill paid by tomato and cotton producers. Thus, for example, it is widely felt that California farm workers are adversely affected by mechanical technology. However, the increase in the demand for harvesting equipment with mechanical harvesting technology increased the returns in the farm machinery manufacturing business. Also, the demand for loans for capital investment by producers increased; thus, the payment to capital increased relative to that of labor.

The impact of technology on real land values is inconclusive since, while increasing productivity and reducing cost, it also decreases product prices in the case where markets are perfectly competitive. However, in cases where output prices are unaffected by technology, the impact on land values is positive. In the agricultural sector as a whole, it is apparent that mechanical-technological change has had a very large impact on the growth in farm size and the reduction in the number of farms.

Alternatively, consider biological-technological changes such as the introduction of hybrid corn and Mexican wheat varieties. In such cases, workers are not necessarily displaced. Employment per acre might even increase because of the extra handling and harvesting of the increased output. If prices do not drop appreciably as a result of the increased output triggering a reduction in acreage, total employment will increase. This appears to have happened in Japanese agriculture where the emphasis on technology was biological in nature; the improved rice varieties seem to have been both labor- and land-intensive. Unlike the case of mechanical change, the capital requirements for agriculture were thus not altered significantly (*6*). Again, however, the effect of biological advances on land values is inconclusive unless product prices stay constant or increase. Finally, it should be noted that biological change, in and of itself, may not force rapid growth in farm size, as in the case of certain mechanical innovations, because there are no indivisibilities requiring large farm size for economical operation.

Compensation: Potential versus Actual Gains

To determine whether or not the overall impact on social welfare is positive or negative, the most common criterion is the "compensation principle"—technological change is beneficial if the gainers can compensate the losers sufficiently so that all are better off. In studies of the impact of the mechanical tomato harvester, it has been demonstrated that there were extremely large gains for producing and consuming groups taken together, whereas displaced farm workers were adversely affected. More interesting than this was the demonstration that the gains were large enough that the farm workers could have been compensated for their losses by the gainers so that "everyone" could have benefited from technological change (*7*). In the absence of other complications every new technological change leads to potential gains for society as a whole because supply is increased. However, if the gains are not adequately distributed, there will generally be groups that are adversely affected and, if society is more concerned about these (possibly poor) groups than the gaining groups, then the actual effect of technological change may not be good. Thus, a more important question than "Is technological change good?" is "How can technological change be implemented appropriately?"

In this context we point out that a substantial amount of technological change in agriculture is of an incremental nature and widely dispersed over time and space so that it is impractical to consider compensation for losses caused by it. Change must be implemented in spite of some losses to specific individuals when the gains are relatively large, otherwise stagnation and the associated lack of upward mobility from the lower-income classes must be accepted. Second, some of the problems of compensation can be partly overcome by extending labor benefits available in other sectors to farm workers. For example, extension of unemployment insurance to seasonal farm workers would provide "generalized" compensation as compared to the "specific" protection of compensating workers for the loss of jobs brought about by the tomato harvester.

Wealth Accumulation and Farm Size

One important issue surrounding technological change concerns increasing farm size and the related accumulation of wealth by landowning farmers. Few would disagree that mechanization has been a critical factor in the process of farm amalgamation. This phenomenon is at least partially explained by the fact that large farmers tend to have easier access to capital markets, information, and education; therefore, they are among the first to adopt new technologies that lower their costs and cause product prices to fall. These phenomena, in turn, create incentives for farmers not adopting these practices to sell their holdings to the larger operations. At the same time, many farms are sold as farm owners reach retirement age; and these farms are often purchased by neighboring farmers who generally need the additional land to make efficient use of ever larger farm machinery. Thus, technological change leads to more concentration in production and may cause monopolistic (or oligopolistic) price practices. If technological change is to be implemented appropriately, it is of the utmost importance that antitrust mechanisms function well to maintain competition. Moreover, these regulations should control the market power of labor unions as well as that of large businesses.

Environmental Impacts of Technology

Increasing mechanization has led to increasing energy demand in the farming sector, and varietal improvements have led to greater use of fertilizers that also embody nonrenewable resources.

Most modern technologies are energy-intensive and contribute to the current energy crisis. However, it could also be argued that, from a social point of view, concern about energy use in agriculture should be secondary relative to wasteful uses such as automobile travel for recreation, jet travel to all parts of the world for trivial purposes, and the manufacture of disposable items.

There has also been a concern that certain technologies result in pollution of the environment. Pollution intensity is not an inherent property of new technologies; with the right environmental policies, science and technology can be harnessed to improve the environment. For example, in California the issue of rice straw burning has resulted in technology now being developed to eliminate the burning process as a means of disposing of rice straw. By using such devices as regulation taxes and health standards, society can control the short-run ill effects of technology and actually create the incentives that lead to long-run technological solutions to particular pollution problems.

Sociological Impacts of Technology

As pointed out earlier, the process of technological change tends to result in the growth of farms over time and, concomitantly, the increased specialization of the factors of production. In many cases the activities of owners, managers, and workers become segmented. For example, Schumacher (*8*) and Mishan (*9*) have recently argued that, because of the emphasis on efficiency and specialization, work becomes repetitious and uncreative. Hence, workers derive satisfaction primarily from wage earnings and not from work per se. But technology has also made possible a large reduction in working hours so that leisure time has become a major source of enjoyment. Furthermore, a number of jobs have been generated in the area of technological development that enhance creativity and self-satisfaction. Net benefits in terms of working conditions are thus difficult to evaluate.

Another major, legitimate concern is the impact of technology on rural communities. Clearly, while many small rural communities declined with the growth of farm size, others survived and grew in size to become major service centers. Under modern transportation there is a reduced value in maintaining adjacent communities.

Certainly, in this process of change, some people have been adversely affected. Older people who could not adjust to large communities and cities suffered. Money was lost in certain businesses since properties in a declining community had little resale value. Thus everyone does not benefit from technological change unless everyone is compensated during the process of adjustment. Also, any compensation scheme must be implemented in a manner that will encourage rapid adjustment rather than channel vast sums of money into declining communities in such a way as to encourage continued social inefficiency. Changes already under way will probably continue to put increased pressure on those in declining communities to move and, if so, the social costs associated with supporting them will increase accordingly.

General Equilibrium Effects

When considering the welfare effects of technological change, one must supplement the above analysis of direct effects with a more general economy-wide analysis of the adjustment process and eventual final state of the economy taken as a whole. For example, agricultural technology has indeed displaced workers, but it is not clear whether workers have been pushed out of agriculture because of dwindling labor demand or pulled out because of more attractive opportunities in other sectors. One way or another, other sectors in the economy eventually absorbed most of the displaced workers. According to U.S. Department of Agriculture statistics, one out of every three people was engaged in farming in order to feed the population in 1910; by 1976, the number had declined to 1 out of every 49. By comparison, approximately 31 percent of the population (which amounts to 70 percent of the 1976 labor force) was freed from farming to pursue occupations elsewhere (*10*). Clearly, this 70 percent has not simply been added to the unemployment lines but has, to a large extent, contributed productively to the rest of the economy. These overall impacts of technology must be evaluated before conclusions are reached about technological change in a single sector.

One cannot omit interregional and international dimensions when discussing technological change. As an example, the mechanical tomato harvester resulted in an increase in acreage planted in California but a decrease in acreage planted in other states because of lower per unit costs in California. Also, since most of California's farm products are traded internationally and labor costs are higher in the United States than many other areas (reflecting a higher standard of living), the United States will not remain competitive unless technology that increases the productivity of labor continues to be developed (*11*).

A further point often overlooked is the effect of agricultural technology on nutrition. The increase in agricultural productivity allowed the people of the United States to consume a greater variety of products; it also increased their consumption of those products having a relatively high protein content. By comparison, lack of technology is a general cause of malnutrition in less-developed countries. Also, the technological improvement in food processing has reduced the hours required for meal preparation by housewives and has thus enabled women to participate in activities outside the home.

Conclusions

It seems that, by and large, the introduction of technology need not lead to undesirable consequences if the process of adoption is properly monitored and controlled. Generally, there are potential gains from technological change; but whether or not all are made better off depends on the extent to which the gainers compensate the losers and the latter are stimulated to adjust rapidly so that losses do not continue. The amount and form of compensation needed depend on such factors as the age of the displaced workers and the level of employment in the general economy.

We suggest that the following points are important:

1) In agriculture it is difficult to identify the workers displaced by a particular technological change. Care must be taken in developing appropriate definitions and in providing incentives for those adversely affected to identify themselves.

2) Compensation must be paid in a manner that preserves incentives to adjust to a changing world. For example, a program that paid a displaced worker the equivalent of his wages until he found another job would not be satisfactory. A better approach would be to provide a simple severance payment, to subsidize retraining, and to facilitate movement to other work.

3) Adequate predictions of the impact of technological improvements present a problem. Preparation of a meaningful "impact statement" prior to the development of a technology is virtually impossible. However, once a particular machine has been developed, a meaningful study can be conducted on its potential impact, the best way to introduce it and control its adverse effects, and the means by which adversely affected groups can be compensated.

4) Part of the taxation or other revenue from the gains of technological change has to be used to finance agencies overseeing compensation and control. In the absence of such use, other bureaucratic costs are likely to result because displaced workers may otherwise be added to the unemployment and welfare rolls that provide no incentives for adjustment.

5) Incentives to entrepreneurs also play a role in increasing productivity over time. If rigid restrictions are continually placed on technological improvements in labor-intensive industries—for example, in the fruit and vegetable industries—then increasing restrictions will entice producers to shift into already mechanized production of other commodities. If handled improperly, such restrictions could thus lead to more expensive foods and less dietary variety. Hopefully, incentives will be sufficiently preserved to ensure that new improvements will continue to be made so that both efficiency and income distribution goals are met. Without efficient means of production there is little product to distribute among the members of society.

References and Notes

1. T. M. Arndt, D. G. Dalrymple, V. W. Ruttan, Eds., *Resource Allocation and Productivity in National and International Agricultural Research* (Univ. of Minnesota Press, Minneapolis, 1977), p. 5.
2. H. P. Binswanger and V. W. Ruttan, *Induced Innovation: Technology, Institution, and Development* (Johns Hopkins Press, Baltimore, 1978).
3. Y. Hayami and V. W. Ruttan, *Agricultural Development: An International Perspective* (Johns Hopkins Press, Baltimore, 1971).
4. R. E. Just and R. D. Pope, *Am. J. Agric. Econ.*, in press.
5. This assertion is based on the fact that the short-run supply curve in neoclassical economics is a short-run marginal cost curve. Under our definition of technological change, the marginal cost of a given incremental unit is lower than without the change; or the same marginal cost is incurred at a higher output with improved technology. Hence, if the supply curve is upward sloping, technological change involves a rightward shift in supply.
6. Y. Hayami and M. Akino, in *Resource Allocation and Productivity in National and International Agricultural Research*, T. M. Arndt, D. G. Dalrymple, V. W. Ruttan, Eds. (Univ. of Minnesota Press, Minneapolis, 1977).
7. A. Schmitz and D. Seckler, *Am. J. Agricu. Econ.* **52**, 569 (1970).
8. E. F. Schumacher, *Small Is Beautiful: Economics As If People Mattered* (Harper Torchbooks, New York, 1973).
9. E. J. Mishan, *The Costs of Economic Growth* (Praeger, New York, 1967).
10. U.S. Department of Agriculture, *Agricultural Statistics*, various issues.
11. Another issue of international dimension relates to farm workers who have entered the United States illegally. If these workers are displaced, one may want to consider a different form or amount of compensation than otherwise. These cases point out the importance of a particular political regime deciding on the extent to which the welfare of those supposedly served by other political institutions will be considered.
12. This article is Giannini Foundation paper No. 544. We thank V. Ruttan and an anonymous reviewer for valuable comments.

AAAS–Newcomb Cleveland Prize
To Be Awarded for an Article or a Report Published in *Science*

The AAAS-Newcomb Cleveland Prize is awarded annually to the author of an outstanding paper published in *Science* from August through July. This competition year starts with the 3 August 1979 issue of *Science* and ends with that of 25 July 1980. The value of the prize is $5000; the winner also receives a bronze medal.

Reports and Articles that include original research data, theories, or synthesis and are fundamental contributions to basic knowledge or technical achievements of far-reaching consequence are eligible for consideration for the prize. The paper must be a first-time publication of the author's own work. Reference to pertinent earlier work by the author may be included to give perspective.

Throughout the year, readers are invited to nominate papers appearing in the Reports or Articles sections. Nominations must be typed, and the following information provided: the title of the paper, issue in which it was published, author's name, and a brief statement of justification for nomination. Nominations should be submitted to AAAS-Newcomb Cleveland, Prize, AAAS, 1515 Massachusetts Avenue, NW, Washington, D.C. 20005. Final selection will rest with a panel of distinguished scientists appointed by the Board of Directors.

The award will be presented at a session of the annual meeting. In case of multiple authorship, the prize will be divided equally between or among the authors.