MORAL RESPONSIBILITY IN AGRICULTURAL RESEARCH

Vernon W. Ruttan

The productivity of modern agriculture is the result of a remarkable fusion of technology and science. In the West this fusion was built on ideological foundations that, from the early Middle Ages, have valued both the improvement of material well-being and the advancement of knowledge.

This fusion did not come easily. The advances in tillage equipment and cropping practices in Western Europe during the Middle Ages, and well into the 19th century, evolved entirely from husbandry practice and mechanization (Asimov; Boulding; Hannay and McGinn). "Science was traditionally aristocratic, speculative, intellectual in intent; technology was lower-class, empirical, action-oriented" (White 1968, p. 79). This cultural distinction regarding the priority of basic science over applied science still persists, although the interdependence of science and technology has eliminated the functional and operational value of the distinction.

The power that the fusion of theoretical and empirical inquiry has given to the advancement of knowledge and technology since the middle of the 19th century has dramatically increased their impact on the integrity of traditional institutions and on natural environments. It is realistic to argue that agronomists, along with engineers and health scientists, have been the true revolutionaries of the 20th century.[1]

THE AGRICULTURAL SCIENTIST AS HERO AND VILLAIN

It has not been difficult to discover heroic qualities in the pioneers who have carried the banners for the agricultural revolution. We can recall many examples:

- Liebig battling to establish the theory of the mineral nutrition of plants and Mendel patiently distilling the elementary laws of genetics from the color of peas in his monastary garden.
- Harry Ferguson, the self-taught mechanic, applying basic physical principles to the integrated design of tractors and tractor equipment.
- Donald Jones finding it necessary to escape from the orthodoxy of the corn-breeding program at Illinois to the obscurity of Connecticut in order to have the freedom to explore the potential value of hybrid vigor.
- The intellectual and physical commitment of Vavilov, the great plant pathologist geneticist wheat-breeder, in protecting the integrity of the Institute of Plant Breeding against the ideological opportunism of Lysenko.

But agricultural scientists have been reluctant revolutionaries! They have wanted to revolutionize technology but have prefererd to neglect the revolutionary impact of technology on society. They have often believed that it would be possible to revolutionize agricultural technology without changing rural institutions. Because they believed, they have often failed to recognize the link between the technical changes in which they took pride and the institutional changes which they either did not perceive or which they feared. As a result, they have often reacted with shock and anger when confronted with charges of responsibility for institutional change—in labor relationships, in tenure relationships, and in commodity market behavior—that were induced by technical change.

In the 1960s and 1970s a new skepticism emerged about the benefits of advances in science and technology.[2] A view emerged that the potential power created by the fusion of science and technology, as reflected in the cataclysm of war, the degradation of the environment, and the psychological cost of social change, is obviously dangerous to the modern world and to the future of man. The result was to question seriously the significance for human welfare of scientific progress, technical change, and economic growth.

Agricultural science has not escaped these ques-

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[1] It will be useful, for the sake of brevity, to occasionally use the term "agronomy" to refer to the whole body of agriculturally related science and technology and "agronomists" to refer to the community of production-oriented agricultural scientists.

[2] For a useful historical perspective, see Shils.

tions. Some interpret the mechanization of land preparation or harvesting as a source of poverty in rural areas rather than as a response to rising wage rates. The milling of grain by the use of wind and water power was counted as progress in 12th century Europe. But today's critics view the substitution of rice mills for hand pounding as destructive of opportunities for work in 20th century Java. There are those who regard the use of fertilizers to increase food production as poisoning the soil rather than removing the pressure of agricultural production on marginal lands and fragile environments. The new income streams that flow from more productive farms are viewed as destructive of the integrity of rural communities rather than as enabling rural people to participate in a society in which the gap between rural and urban income, lifestyles, and culture has narrowed.

What should the agricultural scientist or science administrator make of these charges? Can they be dismissed as the mistaken or malicious rhetoric of romantics, populists, and ideologues?[3] How does one engage in fruitful dialogue about the role of science in society in an atmosphere that is so politically and emotionally charged?

A first step is to recognize that similar economic and social forces have generated both the drive for technical change, leading to advances in the production capacity of plants, animals, machines, and men, and the drive for institutional change, designed to achieve more effective management of the direction of scientific and technical effort and capacity. The increased scarcity of natural resources—land, water and energy—continues to create a demand for technologies that are capable of generating higher levels of output per worker, per hectare, and per kilo-calorie. The rising value that a society places on the health of workers and consumers and on environmental amenities such as clean water, clean air, and clean streets continues to lead to a demand for effective social controls over the development and use of agricultural technology.

RESPONSIBILITY FOR RESEARCH RESULTS

This enhanced sensitivity to the moral and aesthetic as well as the economic implications of technical change imposes expanded responsibility on both public and private decision processes. There is a demand for greater responsibility in the way the results of science and technology are put to use.[4] Should government respond to this demand by changing the institutions that induce the generation of new knowledge and new technology? Should government assume a stronger role in directing and limiting the adoption and use of new technology? Should it attempt to encourage greater aesthetic and moral sensitivity on the part of scientists, engineers, agronomists, and science administrators?

Recent examples illustrate the difficulties that face governments in attempting to respond to the public demand for greater moral responsibility in the generation and use of new technology. The 1970s controversy over the employment-displacement effects of the tomato harvester serves as one useful illustration. The case of research on tobacco improvement represents a second illustration. I have not chosen the two cases because either tomatoes or tobacco are the most significant examples that might be selected. But they do illustrate in a dramatic way principles that are much more pervasive.

Technical Change and Employment Displacement: The Tomato Harvester Case

The introduction of machine harvesting of tomatoes has been accompanied by an especially vigorous debate. It has been viewed as the product of a uniquely effective collaboration between mechanical engineers and plant scientists. It has also been vigorously attacked for its effect in displacing farm workers and small producers, (Rasmussen; Schmitz and Seckler; Friedland and Barton; Just, Schmitz, and Zilberman).

In 1978 a suit on behalf of the California Agrarian Action Project and a group of farm workers was filed against the University of California Regents, charging that they had allowed agribusiness corporations and their own economic interests to influence their decisions to spend public tax funds to develop agricultural machines. The relief sought by the plaintiffs includes an order to compel the University to use the funds it receives from its machinery patents to help farm workers displaced by those machines.

In December 1979, U.S. Secretary of Agriculture Bob Bergland announced in Fresno (California) that he intended to stop USDA funding for research that might put farm laborers out of work, (Marshall). The dean of the University of California College of Agricultural and Environmental Sciences at Davis criticized Bergland for attempting to impose restrictions on the freedom of academic research.

Clearly the farm workers displaced by labor-saving machinery deserve a reasonable degree of protection from unemployment. This is a legitimate claim on the new income streams—the productivity dividends—resulting from the adoption of the new technology. But who among the displaced workers deserves protection? Do the displaced workers who immediately found other employment have a legitimate claim on the new income stream? What about the workers who found other employment but at lower wage rates? And what about the tomato growers in Indiana and New Jersey

[3] For an example of romantic criticisms, see Berry. For a populist perspective, see Hightower. For an ideological perspective, see Lappe and Collins; Valliantos; George. For reviews of this literature, see Eberstad; and Hardin 1979.

[4] Since the late 1960s, the term "technology assessment" has been increasingly introduced into discussions about the distributional, environmental and aesthetic consequences of research and development (See, for example, National Academy of Sciences). There has been considerable confusion over the objectives and methodology of technology assessment. To some it appears to be a new and more powerful methodology designed to overcome the limitations of narrower or more partial approaches to problems of technology generation and choice, while to enthusiasts it was more of a social movement designed to incorporate advances in aesthetic and moral sensitivity into technology design and management. For further discussion see Coates 1975; Coates 1979; Holt; White 1971; and Marchetti.

who lost part of their market due to the lower costs in California? Who should pay the compensation? Should it be the inventors and manufacturers of the labor-displacing equipment? Should it be the farmers who captured the initial gains from lower costs, or the processors who expanded their production as a result of their ability to expand their California operations? Or should it be the consumers who ultimately gained as competitive forces transferred the lower costs of production on to consumers?

The response is implicit in the question. The gains of productivity growth are diffused broadly. The costs should be borne broadly, in the form of generalized rather than specific protection. In a wealthy society such as the United States, a worker should not have to prove specific displacement—that he or she was displaced by a tomato harvester or a Toyota—in order to be eligible for such protection.

The first line of defense against the impact of displacement is an economy in which productivity is growing and employment is expanding. Society has little obligation to compensate the worker who can readily find alternative employment. The second line of defense is a program of severance payments and unemployment insurance that is effective for all workers, those who are forced to seek seasonal or casual employment as well as those in more favored industries.

A society that provides generalized protection will be in a stronger position to realize the gains from technical change and to diffuse these gains broadly than a society that insists on specific or categorial protection.[5] The failure to develop institutions capable of protecting farm workers from the effects of seasonal unemployment and technological displacement has resulted in the transfer of an excessive burden of displacement costs on farm workers. This, in turn, has induced a legal and political response that, if effective, could slow technical change and limit the gains from productivity growth.

In a society in which employment opportunities are expanding rapidly and protection from unemployment is adequately institutionalized, neither the individual researcher or the director of the research team involved in the development of a tomato or a lettuce harvester needs to be excessively burdened by the moral implications of trade-offs between the economic and social costs and the benefits of mechanization. Public policy has relieved them of that burden. But who should bear the burden of responsibility in a wealthy society that forces the burden onto its poorest citizens?

Efficiency in the Production of a Health Hazard: The Case of Tobacco

Tobacco is a commodity that has been the subject of moral debate and political intervention since it first became a commercial export from colonial America. In the 1950s and 1960s conclusive evidence was produced of the association between cigarette smoking and lung cancer, coronary artery disease, chronic bronchitis, and emphysema. The source of health hazard is due to nicotine and related alkaloids.[6] What are the moral responsibilities of agricultural researchers and research administrators regarding a crop that not only induces chemical dependency, but which also kills people—which has a high probability of shortening the life of those who consume products that are made from it?

One would, under these circumstances, think that efforts to develop tobacco varieties with low nicotine content would have the support of both farmers and consumers. Yet a successful effort in the early 1950s, by Professor W. D. Valleau of the University of Kentucky to develop low-nicotine varieties of tobacco was bitterly attacked by Kentucky farmers because of potential competition with burley tobacco (Hardin 1976). In retrospect, we have little difficulty in sympathizing with the objectives of Professor Valleau's research. Even a marginal contribution to the reduction of chemical dependency and health hazards of cigarette smoking would seem to be desirable.[7] But what about the issue that underlies this judgement?

Should public funds be used to do research to reduce the costs and improve the productivity of a product that induces chemical dependency or shortens life expectancy? What are the moral responsibilities of the directors of the agricultural experiment stations in the states that support tobacco research? And what about the individual scientist who devotes his life to understanding the physiology or the nutrition of the tobacco plant? Is the farmer who grows the tobacco absolved from responsibility by the fact that there is a market demand for tobacco? Are members of the legislature and the experiment station director absolved by the fact that tobacco has been one of the more profitable crops available to small farmers in the depressed areas of Kentucky or North Carolina? Are the scientists relieved of responsibility by an appeal to the freedom to do research? What are the moral implications for the tobacco breeder, whether employed by a private firm or a public research institution, of responding to market criteria-when the market is most effectively enhanced by inducing chemical dependency? What inferences can be drawn about moral responsibility from the behavior of a society in which the government spends billions of dollars on health care made necessary by smoking, millions of dollars on research on tobacco-related disease and on campaigns to discourage smoking, yet also supports research to improve efficiency in tobacco production and legislates programs to support the incomes of tobacco producers?

[5] For a useful discussion of the constraints on the feasibility of a general policy to provide specific protection, see Pasour. For a more positive view, see Rausser, de Janvry, Schmitz, and Zilberman.

[6] For a definite review of the evidence, see U.S. Public Health Service.

[7] Tobacco breeders have now gone well beyond Professor Valleau's limited objectives. At present it is possible to manipulate the nicotine content within a very broad range without significantly altering the yield potential. The ability to manipulate the chemical characteristics of tobacco is probably more advanced than understanding of the health implications of the several characteristics. Over the next decade or so, technical and institutional changes in tobacco harvesting and marketing are likely to result in substantial labor displacement along the lines described in the tobacco harvester case (Smith).

There are, as in the case of the tomato harvester, institutional changes that would relieve research administrators and scientists of the moral dilemma posed by tobacco research. If a public consensus were to result in making the sale of tobacco products illegal in the U.S., it is doubtful that the directors of the Kentucky and North Carolina state agricultural experiment stations would allocate any more resources to tobacco improvement than they now allocate to marijuana research. There has not yet been sufficient convergence of opinion to take the steps that would be needed to limit the content of dependency-forming or carcinogenic substances in cigarettes. An attempt to move toward complete prohibition would require a careful balancing of the desirable effects on individual health against the undesirable effects of attempts to enforce prohibition.[8]

TOWARD SOME GUIDES TO MORAL RESPONSIBILITY

The tomato and tobacco research cases pose extremely difficult moral problems for agricultural researchers and research managers. The centuries-long struggle in western society to free scientific inquiry from the constraints of the church make it unlikely that the answers to issues of moral responsibility for new knowledge and new technology will be sought from traditional religious sources.

Where, then, can the scientist or science administrator look for guidance on issues of moral responsibility?[9] One possibility is a philosophy of inquiry approach that recognizes the objective status of both positive and normative knowledge. The philosophy of scientific inquiry to which most scientists subscribe, either explicitly or implicitly, imposes only two criteria as a test of *objective knowledge: correspondence* and *coherence*. The test for *correspondence* requires that knowledge be continually tested against experience and observation. The test for *coherence* requires that the scientific explanation meet the test of *logic:* that it be explainable in terms of our general knowledge of scientific principles.

This view of scientific method, known as logical positivism, has been of great significance in leading to the quantification of scientific knowledge. Biometricians, econometricians, and others are able to clearly distinguish between the logical structure of their concepts, which can be tested for coherence, and the empirical content of their statements, which can be tested for correspondence. A limitation of logical positivism is that it tends to ignore normative knowledge, knowledge about what is good or bad. Indeed, it is a fundamental principle of logical positivism that there is no empirical, objective, or true knowledge of the normative.

The recent social criticism of science can be interpreted as a challenge to this view. It has also been challenged by some philosophers of science who draw an analogy between the tentative "dialectical" nature of positive scientific knowledge, which must be continually tested for correspondence with empirical observations, and the tentative nature of normative knowledge. They argue that normative experience, such as the goodness of a healthy body or the badness of injustice, implies that normative knowledge can also, in principle, be tested against the criteria of coherence and correspondence. Like positive knowledge, normative knowledge is always tentative and must be continually tested and retested for correspondence and social behavior.

Acceptance of comparable objectivity of positive and normative knowledge does not, however, lead directly to prescriptions about right or wrong behavior. It is not always wrong to do what is bad—if it is the least bad that can be done under the circumstances. Nor it is always right to do what is good—if something even better can be accomplished with the same, or less, effort or resources. Thus, the knowledge that cigarette smoking has bad effects does not automatically imply a decision that cigarette smoking should be prohibited. A decision to prohibit cigarette manufacture and trade would involve a weighting of the good effects of less smoking on chemical dependency, health, and longevity against the bad effects that might be induced, such as the corruption of the legal system and the loss of personal freedom.

Any decision rule that transforms knowledge about what is good or bad into a prescription about what should be done implies the use of both normative and positive knowledge. Such decisions involve both positive and normative knowledge about the consequences, for example, for agricultural production, for human health, for the incomes of hired laborers and farm operators, for the cost of food to consumers, and for the economic and political status of scientists, bureaucrats, and politicians.

Only modest progress has been made in evolving a set of tested normative knowledge that can serve as a basis for workable prescriptions. Yet one can perceive, in the public discussion of the tomato harvester and tobacco research cases, two principles that appear to have fairly broad applications in interpreting a wide range of individual and group behavior in response to issues of moral responsibility.

The first is that a risk or loss that occurs incrementally is associated with less personal concern and induces weaker public response than a risk or loss that occurs in more discrete or lumpy units. Most smokers seem willing to accept the statistical evidence that cigarette smoking reduces average life expectancy. But almost no one believes that smoking one more cigarette or waiting one more week to stop smoking will have an effect on his or her own life expectancy. In contrast, the loss of a job as a result of the mechani-

[8] It is doubtful that prohibition of tobacco use would be any more effective than the attempts that were made in the 1920s in the United States and Finland to prohibit the consumption of alcoholic beverages. It is of interest to note, however, that in 1980 Malaysia imposed rather severe restrictions on the advertising of alcoholic beverages and cigarettes. The restrictions on tobacco advertising have been less severe than on alcoholic beverage advertising primarily because tobacco is produced by large numbers of small farmers.

[9] For a discussion of these issues within the context of energy policy, see Johnson and Brown.

zation of a harvest operation or the displacement of domestic employment by imports is a discrete and often a very painful event. It often generates a substantial political response, even when the number of individuals affected is relatively small.

A second principle is that there is an asymmetry between gains and losses. The utility of an incremental gain in income or in the control over an environmental amenity is less than the utility lost from an equal incremental loss in income or loss of an environmental amenity. This asymmetry leads to stronger political action to prevent income or quality deterioration than to achieve income on quality gains (Hardin 1982).

A third principle is that there is a stronger held belief that government has a clear responsibility to protect citizens against damage or loss imposed on them by either the purposeful or unintended actions of others. In contrast is the belief that government has only limited responsibility for protecting citizens against the damage that they do to themselves. The smoker who is willing to acknowledge the effect of his habit on life expectancy may also insist that smoking is a matter of personal choice and may be willing to defend tobacco research that will provide him with less expensive or better cigarettes.

While the three principles suggested above appear to correspond to a great deal of personal and group behavior, they have not been subjected to rigorous tests of correspondence or coherence. An implication of the emerging philosophy of inquiry perspective is that the continuous testing and evaluation of the values implicit in individual and group behavior could lead toward the normative knowledge needed to evolve a body of workable prescriptions in the field of science policy.

TECHNOLOGY AND REFORM

A necessary step in any effective response to the public concern about the social impact of technical change is for the research community to agree that there can be no question about society's right to hold scientists, engineers, and agronomists responsible for the consequences of the technical and institutional changes set in motion by their research.[10] When credit is claimed for the productivity growth generated by advances in agricultural technology, responsibility cannot be evaded for the effects on the distribution of income between suppliers of labor, land, capital, or industrial inputs. Nor can responsibility be evaded for the impact of, for example, pest control chemicals on environmental amenities or on the health of workers and consumers.

Once the right of society to hold its researchers responsible for the effects of the knowledge and technology they provide is accepted, it is then possible to deal with the more tractable question concerning how much responsibility a wise society will impose on its research community. I argue here that *it is in society's interest to let the burdens of responsibility rest lightly on the shoulders of individual researchers and research managers.* If society insists that it be assured that advances in agricultural technology carry minimum risk, and thus that agricultural scientists abandon their revolutionary role, society must accept the risk of losing access to the new income streams generated by technical change.

Society should, for example, exercise great care in insisting that research managers and scientists commit themselves to the realization of scientific or technical objectives that are unrealistic in terms of the state of scientific and technical knowledge. It was unrealistic in the 1950s to expect that utilization and marketing research could make a significant contribution to the solution of agricultural surplus problems in the United States. The allocation of excessive research resources to these areas led both to a waste of research resources and to erosion in the credibility of the research enterprise.

It is equally wasteful for society to ask agricultural research managers and scientists to adopt objectives that are not revealed in the economic or political market place. It is unrealistic, for example, to insist that the California Agricultural Experiment Station direct its mechanization or its biological research to the needs of the 160-acre farm—unless the State of California or the federal government is prepared to support the structural policies necessary to reverse the trends towards large-scale agriculture. A research system cannot be asked to produce knowledge and technology that will not be used without eroding the intellectual integrity and ultimately the scientific capacity of the research system.

It might be argued, against the above position, that policy makers should insist that research managers direct social science research to "discover" society's true objectives (a social welfare function) prior to the time that they are "revealed" in the political or economic market place. This implies that the research manager should have on his staff the analytical capacity not only to assess the incidence of the benefits and burdens of the technical changes anticipated from a research program, but also to develop a set of normative weights (shadow prices) that reflect the "true" value society places on the welfare of each individual or group that may potentially be benefited or burdened by the results of the research. The incidence estimates and the welfare weights could then be combined in making research resource allocation decisions. This view suggests that research directors should allocate resources on the basis of a social welfare function prior to the time it is revealed by either the economic or the political system!

How do I suggest that research managers respond to the social concern about the impact of technology on society? I do insist that research directors should have access to the analytical capacity to gauge the potential

[10] This is consistent with the view expressed by Mohr. Mohr notes that "freedom of inquiry . . . does not necessarily imply freedom in the choice of any particular goal; it implies, however, that the results of scientific inquiry may not be influenced by any factor extrinsic to science." (p. 48)

incidence of benefits and burdens. This will enable them to enter into effective dialogue with the potential system about research budgets and priorities. The research director who does not have access to or fails to use such capacity stands naked before critics and supporters. Research leading to a better understanding of the discrepancies or the disequilibrium in the economic, political, and social weighting system is essential. But the objective of such research should not be to provide research directors with the weighting system for internal research resource allocation. The objective should be to contribute to a political dialogue that will result in institutional changes leading to convergence of the several weighting systems. As these weighting systems converge, research directors will not be forced to choose among alternative responses to an arbitrary or inconsistent set of economic, political, and social weights.[11]

Research managers do have a clear responsibility to inform a society of the impact of pricing systems and tax structure on: (1) the choice of mechanical, chemical, and biological technologies by farmers; (2) the incidence of technical change on the distribution of income among laborers, landowners, and consumers; (3) the structure of farming and rural communities; and (4) the health and safety of producers and consumers. They also have a responsibility to enter the intellectual and political dialogues that are necessary if society is to achieve more effective convergence between market and shadow prices and between the individual and revealed preferences of its citizens.

If market and shadow prices for inputs and products can be made to converge, research directors can be given clear signals for the allocation of research resources. When market and efficiency prices diverge, it will be almost impossible to induce research planners to allocate their resources in a manner consistent with the shadow prices. If political processes can lead to greater consistency between revealed preferences and individual values, individual scientists and research managers might no longer be confronted by a situation in which cigarette smoking is branded as dangerous to health and at the same time public resources are appropriated for research on tobacco.

In taking this position, I wish to express one major qualification. I am aware of few research directors who make adequate use of the knowledge available to them within their own institutions to provide themselves either with the positive knowledge on what is scientific and technically feasible, or with the normative knowledge about the potential value of the new knowledge and new technology.

AGRICULTURAL RESEARCH AND THE FUTURE

What should society expect from agricultural science in the future? And what does agricultural science have a right to expect from society if it is to meet society's expectations?

Let me comment first on what society should expect from agricultural science.

First, society should insist that *agricultural* science maintain its commitment to expanding the productive capacity of the resources used in agricultural production. These included the original endowments, or nature, the soil, water, and sunlight; the agents that man has domesticated or adapted for his purposes, plants and animals and organic and mineral sources of energy; the agents he has invented, machines and chemicals; and people engaged in agricultural production.

It is essential for the future of man that by the end of this century the capacity to maintain this commitment be established in every part of the world. During the last two decades, the world has become increasingly dependent on the productive capacity of North American agriculture. This dependence poses danger both to the developing world and to North America. Agricultural science communities and institutions capable of producing the knowledge and the technology to reverse the trends of the last several decades must be established. Agricultural science in North America must remain strong enough and sufficiently cosmopolitan to contribute to and learn from the emerging global agricultural science community.

Second, society should insist that agricultural science embrace a broader agenda that includes a concern for the effects of agricultural technology on the health and safety of agricultural producers; for the nutrition and health of consumers; for the impact of agricultural practices on the aesthetic qualities of both natural and man-made environments; and for the quality of life in rural communities. It must also consider the implications of current technical choices on the options that will be available in the future.

These concerns are not new for agricultural science. But they have often been viewed as peripheral or diversionary to the main task of agricultural research. It is important for the future of agricultural science that these concerns be fully embraced. It is also important that the capacity to work on these problems outside of the traditional agricultural science establishment be maintained so that an effective dialogue can be achieved both within the research community and in the realm of public policy.

What should the agricultural science community expect from society?

First, agricultural science should expect that society will gradually acquire a more sophisticated perception of the contribution of agricultural technology to the balance between man and the natural world. The romantic view that agricultural science is engaged in a continuous assault on nature is mistaken. Society must come to understand that agricultural science can succeed in expanding productive capacity only as it reveals and cooperates with the laws of nature.

We in the West are the inheritors of a tradition that

[11] The position expressed here is similar to that presented by Steiner.

views material concern as a defect in human nature. This inheritance leads to a romantic view of man's relationship to the natural world. It also leads to a view that technology alienates man from both the natural world and from the natural community. Scientists, engineers, and agronomists have a right to expect the philosophers of society to achieve more sophisticated insight into man's relationship to technology and nature. It is time to recognize that the invention, adaptation, and use of knowledge to achieve material ends does not reduce experience, but rather expands it.

Second, it is time for the general science community to begin to follow the lead of the agricultural science community in embracing the fusion of science and technology rather than continuing to hide behind the indefensible intellectual and class barriers that have been retained to protect its privilege and its ego from contamination by engineering, agronomy, and medicine. This change will become increasingly important in the future as the close of the fossil fuel frontier joins with the close of the land frontier to drive technical change along a path that implies a much larger role for biological and information technology.

The 1970s was a period of declining productivity growth in the United States and several other advanced economies. These dangerous trends were more apparent in the industrial than in the agricultural sector in a number of developed economies. Rates of return to agricultural research have remained high. The evidence suggests that institutional linkages that have provided effective articulation between science, technology, and agriculture have continued to be productive sources of economic growth in both developed and developing countries. There is much that can be learned from this experience by those who are not blinded by outmoded status symbols or cultural constraints.

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