TECHNOLOGICAL CHANGE:

THE FARM AND FOOD SYSTEM IN TRANSITION

BY

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ABSTRACT

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The paper gives an overview of the impact of new technologies on the performance of the farm and food system in the United States. A theoretical framework is outlined. Two major technological frontiers are then discussed. Microbiological breakthroughs are representative of technologies which shift the production function. Computer and communications advances help management by reducing transactions costs. These and other new technologies are discussed at each level of the farm and food system. Key policy issues and future research topics are finally addressed.

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I. INTRODUCTION

The rules by which a society controls the interactions of its members are established as governmental law and as custom. In a democratic political economy this rule-making is done collectively. Individuals and groups in our society articulate their preferences in both the marketplace (for goods) and in the political system to change the rules to their favor. Neither system, the market nor the political system, is perfect. We are thus constantly changing our institutions to satisfy our desires. Overt changes, such as changes in a voting rule or the regulation of a market, are important as are the subtle cultural shifts from one institutional arrangement to another.

Technological change is often the reason for a perceived need to change institutions. Institutional economist James Shaffer stated: "[Determining the institutional structure] is an evolutionary process in which the political system responds to perceptions of performance with changes in the rules of the game. New technologies continually alter the opportunity set and require continual adjustments in the institutions."[1]

Technology is all around us. "Technology is all we have," exclaimed Buckminster Fuller, one of the great technologists of this century.[2] He went on to explain that with additions to human knowledge, inventions, and the development of new machines, man is capable of doing "more with less". Technological advances allow us ultimately to meet our needs using fewer materials and less energy. The agricultural production, processing and distribution which comprise the farm and food system are no exception. What technologies are being developed, which ones will be employed, and what impact new technologies will have on farm and food policy are concerns of this paper.

The farm and food system encompasses thousands of processes and techniques as varied as spot welding a tractor on an assembly line and serving a glass of orange juice at an all night diner. A technological change in the farm and food system will bring about changes on several levels of the system: the supply of various commodities, the structure of industries, and ultimately our institutions will be affected.

To address this topic adequately, we must examine the potential technical changes at each level of the food and farm system and limit our discussion to the important ones. These tasks are not simple. The actors we will discuss can be categorized with respect to their level in the farm and food system. The system is composed of:

1. input suppliers
2. agricultural producers
3. food processors (including assemblers and manufacturers)
4. food distributors (including the wholesalers and retailers)
5. consumers

The technologies themselves are categorized only with great difficulty. It will be readily apparent to the critical reader that no technological change is easily slotted. Some 'scientific license' has been taken in order to present a framework of analysis. A scientific ordering is less important than one allowing policy makers, leaders of the farm and food system, and informed citizens to discuss these changes and the impact they will have on the system. From there the discussions with respect to technology and food policy can take place at a higher level.

In order to organize the material this paper considers the following categories:

1. biological
2. electronic
3. chemical
4. mechanical
5. resource conserving technologies
6. technologies which affect health and safety

Successive sections of the paper will present first a survey of the literature on the theory of technological change. The purpose of this section is to give the reader an appreciation of the problems of definition and measurement which plague economists who deal with technological change. Philosophical problems which extend well beyond the boundaries of this paper are only mentioned. The inherent dynamism of techological change forces one to push the limits of definitions and analytical techniques which have been developed under more stable assumptions.

Two technological changes appear in the next section of the paper. Microbiology and computer and communications technologies are the frontiers in which the greatest changes are presently taking place. Microbiological technologies shift the production functions outward. Costly inputs are conserved and greater production is achieved for given level of inputs. Computer and communications technologies are of a different sort. Transactions costs are reduced and management decisions can be made inexpensively when the speed and volume of information flows are increased.

The significant technological changes at each level of the farm and food system are discussed in the next part of the paper. Certain technologies which affect the interaction between these levels are discussed. The final section of conclusions presents a summary of the impact of the changes on the existing institutions. Institutional changes and topics for future research are suggested.

II. PERSPECTIVES ON TECHNOLOGICAL CHANGE

The economic actors in the farm and food system respond to the signals of the economy by conserving scarce resources. The scarce resources are those which have a marginal value product equal to or less than their marginal factor cost. That is, by employing those resources the firms are just breaking even or losing money due to recent changes in factor costs. In response to a costly factor of production, firms will try to conserve that factor and employ others in its place. Our economy is thus in constant flux as certain factors become scarce relative to others for particular production processes. Technological advance is defined as the development of new knowledge which may or may not be applied. Technological change involves the application of knowledge to develop techniques and the adoption of these techniques. Technological change occurs at the firm level when the entrepreneur responds according to these neoclassical principles. Technological change includes minor and major shifts in the mix of labor and capital.

A theory of technological change must encompass the creation of new knowledge and its technological application. Economists are interested in both the advance of pure science and the adoption of applied science in the form of new technologies.

Economizing is conserving in the very broad sense. At times the entrepreneur will find it in his interest to conserve labor, at other times a capital input will be in short supply. Reduction of commodity wastage, recycling, reduction of inventories, higher yields per energy input, and disease resistant plant varieties all allow producers to get more output with the same inputs or the same output with fewer inputs.

The reasons for technological change are still under dispute. Certain economists feel that technologies are developed relatively independently of the factor prices. Whole new techniques are introduced, new products are developed, and then they are marketed without substantial regard to the factor prices. An example of this would be a the home computer which was not developed as a result of consumer demand or in response to a high factor price.[3] Induced technological innovation, on the other hand, refers to the development of a new technology in response to changes in relative factor prices. In this case each technological change is implemented by an individual or firm because the specific mix of factors accomplishes a given production process in a least cost method.

Present technology shifts are related to the shifts which occurred in relative factor prices in the early and mid-1970's. Energy is used in the industries which supply the tools and machines of the farm and food system. Escalating energy prices are to a large extent responsible for these changes. Entrepreneurs are investigating energy conserving technologies. In some cases they conserve direct energy inputs into the system and in other cases they conserve energy indirectly. This paper will investigate both the induced changes and those which involved the introduction of a new product.

Productivity changes occur when new technologies are used. Productivity levels are a measure of how much product comes from a given amount of inputs in a production process. Labor. and total productivity figures are usually quoted. Labor productivity is the most common because economists are concerned with raising the amount of product a given laborer can produce. Reliance on this measure may lead to overcapitalization in some societies. Total productivity measures consider all of the scarce factors of production. A total productivity measure is one way of comparing different economies. There are problems in this measure, however, because many labor and capital are fundamentally different and hence not easily compared. Comparisons made in terms of prices rather than amounts may not be valid because relative prices depend on the distribution of wealth and human preferences.

Basic and applied research as well as the learning which occurs by doing are responsible for the increases in the amount of knowledge we have. New knowledge can result in the development of a new technology. A new technology usually requires expenditures of capital and retraining of workers to become viable. A firm presently producing a good will have to deal with the transition from the existing capital stock to a new one. Technological change and increases in productivity are possible through the investments made by public and private organizations.

John Kendrick and other economists have considered both the capital and human investments necessary for productivity increases.

> All outlays that contribute to output- and income-producing capacity (capital) for future periods may be defined broadly as investment. This definition does not only include the outlays for tangible structures, equipment, inventories, and development of natural resources, which are traditionally considered to represent capital formation; by analogy, it could also include the cost of rearing children to working age, that is, the formation of tangible human capital. But it is the intangible investments designed to improve the quality and efficiency of the tangible nonhuman and human factors that are of particular significance in explaining productivity advance.[4]

Kendrick also notes other reasons for productivity increases. Internal and external economies of scale which allow specialization and the spreading of overhead; the degree of economic efficiency; and inherent changes in the quality of human and natural resources not due to investment, each contribute to productivity.[5]

Technological changes and changes in productivity are closely linked with the concept of efficiency. Efficiency is an often misused concept because of the various definitions which occur in the world of the engineer, the economist and in everyday parlance. Economists refer to technical efficiency as a measure of how close a production process is to a frontier production curve. Allocative efficiency is their measure of how well resources are allocated given the relative product prices and factor costs of the marketplace. Economic efficiency is then the product of these two.[6]

These definitions are ultimately inadequate for two reasons. First, the definitions which economists use for convenience are grossly oversimplified. Different production processes are just that: different; and hence they cannot be rigorously compared. The classical two-dimensional production function used in classrooms and published papers is fine for pedagogical purposes; however, no real world production process has only one or two inputs.

Multidimensional projections of production functions quickly become too complex for even the best analytical methods and computers to estimate and display. In fact, neoclassical theory is yet unable to adequately handle time and energy flows. Economist Kenneth Boulding expresses some of these problems succinctly:

> An increase in the know-how . . . of course, may change all the limiting factors, for they all interact with each other. Hybrid corn, for instance, certainly economizes space. It also economizes time, being quicker and easier to harvest. It may even economize energy input, utilizing more solar energy and less muscle or fossil fuel power, but I am not sure of this. It probably did not economize materials, but increased the necessity for artificial fertilizers. What we have here is a complex shift in the fences that crisscross the productivity hill. They are by no means easy to unscramble. Unscrambling these effects would be much more rewarding than trying to develop Cobb-Douglas production functions, or any kind of constant parameter function. Sometimes, indeed, the most important limiting factor could be an undetected trace element.[7]

The neoclassical definition of efficiency is also inadequate because it assumes a given distribution of resources and hence is a normative proposition. Different distributions of resources yield different efficient points because the relative wealth of the actors determines the relative prices and hence the point of allocative efficiency.[8]

We are ultimately concerned with the policy questions which arise due to the application of new technologies. Productivity and efficiency concepts are often the basis of argument in policy discussions. One important policy question is the impact of a given technology on the structure of industries and on the relative market power of the actors at various levels. A given firm is interrelated with other firms in the system and the technologies which the firm employs likewise have various impacts on the other firms. In imperfect markets other technologies will increase the power of one set of producers over another and the benefits of technology may be captured rather than passed on to the consumer. Economists refer to the effects which occur outside a given firm as the externalities. Technological change is bound to bring with it changes in these external effects. Externalities can be technological (they have a physically measureable impact) or pecuniary (they change the relative prices of factors and commodities). Externalities are ubiquitous. The externalities of a given firm may be insignificant; however, the externalities of industries and the various levels in the farm and food system will be measureable at the national level.

Whether a firm must compensate those who lose due to a new technology they employ is an issue of property rights. Compensation is required where the rights are clearly established. The law is seldom that explicit, however. Where technological change introduces unforeseen external effects, public policy will need to deal with the aggrieved parties. The technologies developed as a result of these funds will cause pecuniary and technological external effects. Redistributions of wealth which are indirectly caused by public expenditures need to be addressed publicly as well. Since economic efficiency concepts take the distribution of rights as given, they may bias our analysis in favor of the status quo. Where efficiency concepts are used the writer should be careful to specify the assumptions which have been made--both those about the distribution of resources and simplifying assumptions about the number and kinds of inputs.

Ultimately, public choice must rely on the government to control private firms without adversely affecting innovation. How a society chooses to evolve depends on the rate at which new technologies are introduced. Shaffer has stated that:

> [Determination of the optimum rate of technological change] is closely related to a society's capacity to deal with 'external effects' of technological change through institutional innovation and compensating public policies. The rate of adoption depends upon the manner in which effects are internalized.[9]

Our understanding of change in economic systems is at best sketchy. Economists' methods of measuring the impact of technology on productivity are primitive. Generally, the residual which cannot be explained by any other means is assigned to technological change.[10] This residual is thus a measure of ignorance rather than a measure of what we understand. In many ways our understanding of the interactions of human knowledge and the material world is inadequate to develop a sound theory of technological change.

Neoclassical economics has taken a mechanistic view of the world and has tried to explain the intricacies of a complex society through systems of equations. Boulding refers to the evolution of the economic system as similar to the biological evolution of which we are a product:

> Evolution takes place by the filling of empty niches. There is no guarantee that empty niches will be filled before they close. This introduces a profound element of indeterminacy into the system, and any attempt to reduce it to a kind of Newtonian mechanics is bound to fail, simply because it is not that kind of reality. This is why, for instance, empirical attempts to explain development in terms of land, labor, and capital production functions have been so unsuccessful. We have always had to fall back on some vague concept of technological change, which is a kind of surrogate for the genetic knowhow factor.[11]

Many economists have gone beyond the limitations of neoclassical theory to deal with technological change. A large body of literature exists on the diffusion of innovation for both agriculture extension and the application of new techniques in other areas as well. The theories state that where a new technology is developed there are those who will be more able and willing to be the first to try the technology. These innovators will collect the economic rents which accrue to those who are able to lower their costs and continue to sell their product at the market price. As the majority of producers implement the new technique the market price will fall in a perfectly competitive market. Producers are thus forced to use the technology in order to survive. Finally, laggards are forced out of business as the innovators price their products below the costs of those who have not employed the technique. Technological change can thus have a significant impact on the structure of an industry.

The application of an invention within the farm and food system may occur only after a substantial period of time. The reasons for this are manyfold. In the case of certain technologies, there may be an inherent physical lag which must occur before they can be applied. For example the growing season of certain crops may cause a lag period. In another case, the use of a technology in one portion of the system may depend upon coordination with other parts of the system. A technology may be applied only after a period of time when adjustments are being made in the system. Other technologies may be developed in anticipation of changes in factor prices which never occur.

Each technology must be examined with respect to the ability of firms to change their production processes. We cannot say whether a new technology will cause more or less concentration in an industry without examining the specific technology. Certain technologies may require huge capital expenditures, advanced research and development expenditures and a corporate commitment which will force out the smaller firms in an industry. Other technolgies may permit smaller firms to compete more agressively with the larger ones.

Certainly, if a technology cannot be implemented in a profitable way it will "never get off the drawing board" in the private sector. There are as well a significant number of technologies which have been developed at a scale appropriate for the laboratory, but which require further development before they can be applied at the firm level. The adoption rates of particular technologies will depend on a number of factors. Firms are faced with the prospect of shifting their capital assets from one production process to another. This may be costly and would depend on the opportunity cost of money in the financial markets, and the salvage value of their capital assets. Adoption of a technology will depend on its complexity and the relative advantage to firms of absorb this technology. Retraining of the firm's workers may be very costly. Certain firms may have an advantage with respect to their ability to manage the flow of new information. The riskiness of technologies will also depend on whether the technology is a new one or one in which the managers have had previous experience. Adoption rates will thus be a function of several uncertainties: the relative financial position of the firms in an industry, their view of the technology with respect to its certainty of success and the costs which they expect in the future.

A variety of institutional constaints may restrict the adoption of certain technologies.

Government regulations apply to a wide variety of environmental and health matters which are of concern to firms in the system. Regulations may restrict the application of certain processing technologies. Firms are less likely to attempt to try a new technology if they foresee extensive litigation. The government, however, is not likely to permit the consumers to be used as the testing ground for new techniques.

Patent laws also restrict the application of technologies but are called for where they permit a firm to reap the benefits of a long research and development procedure. In certain areas, such as the development of new forms of life through genetic engineering, there remain uncertainties which will be decided as the field expands.

Institutions have an impact as well on the attitudes of people toward risk, willingness to adapt to change, propensities to save and invest. Antitrust laws, regulation of public utilities, social legislation, macro policy (fiscal, monetary, incomes) and its effect on after tax incomes are also important.[12]

Research for the farm and food system is conducted both privately and publicly. The political economy of reseach funding is a complex issue. The private expenditures are generally common in those processing firms which are capable of implementing a new technology on a large enough scale to pay for the research. Public research is conducted in the land grant universities and at other universities and research organizations which are able to secure government funding. At times the reseach is basic with little prospect of payoff in the short run. The results of this research are later used by more applied scientists in either the public or private sector. Applied research in the public sector is ostensibly to help the consumer by raising the productivity of the farm and food sector in the long run. At times, however, the research has as its primary beneficiary a firm which is able to implement the technique in the short run and capture the benefits.

All technological change, whether it is labor saving, capital saving, or neutral, operates within the institutions which evolve as a matter of public choice. In some cases technical change will occur simply due to a change in the institutions. While the institutions are important to the development of technologies, one should not think of institutions as causing technical change. Our chosen institutions and technologies are interdependent and interact continually. Different institutional configurations will give different results with respect to the specific technologies applied and to the innovative characteristics of society. Techniques are developed in response to the desires of individuals to improve their standard of living, obtain more power, gain respect--for a variety of reasons. The techniques are successfully applied or not, as a result of the relative factor prices and the concurrent demand which is established as a result of marketing strategies.

With these thoughts in mind one can examine the specific technologies which will have an impact on the farm and food system in the 1980's and 1990's.

III. TWO NEW FRONTIERS

There is significant agreement among scientists and other leaders in the food and farm system that during the next seventeen years the largest productivity gains will be registered in two areas: agricultural and industrial microbiology and computer/communications technology. These two areas of inquiry are certainly not limiting. Many other important technologies will soon be applied. However these two are unique in the depth of impact which they will have on all levels of the farm and food system.

Most experts agree that many commercial application of agricultural microbiology technologies will not be widespread until the later part of the 1990's. The techniques have been under investigation for several years and scientists are now confident that further research efforts will begin to provide economic applications.

Computer technology has been with us for several decades. The cost of memory units has fallen constantly, permitting a variety of profitable business applications at all levels. Microcomputers are now affordable at the household level and in schools. The children of today are becoming computer literate in addition to learning the "three R's." Computer literacy may well be necessary in the next decade as business uses expand and as microprocessors are a part of most of the products which we use in work and at play.

MICROBIOLOGY

Agricultural and industrial microbiology includes the engineering of molecules to increase crop and animal production, to allow energy production from wastes, and to permit the manipulation of microorganisms to produce a wide variety of goods. New crop technologies are focused on conserving nitrogen fertilizers, accelerating photosynthesis, and developing crops which will grow in harsh environments such as saline or acid soils. Bacteria and other lower life forms may be developed which improve the fermentation of alcohol, produce animal feeds from wastes, diagnose animal diseases, and produce plant and animal hormones. Ultimately, genetic engineering techniques may allow the cloning of farm animals.

Corn production in the United States uses one billion dollars per year for nitrogenous fertilizers. The development of crops and crop/microorganism combinations that fix free nitrogen from the air would represent a great savings in the production of corn and other crops. Improving the efficiency of photosynthesis is important to boost crop yields directly and indirectly by providing more energy to the nitrogen fixation process.

Microbiology is comprised of three techniques for agriculture.[13] First, microorganisms which are beneficial to the plants can be grown and introduced into the soil. A common example of this is the introduction of the bacteria Rhizobium, packaged with peat, into crops such as beans, peanuts, alfalfa, soybeans and peas. This bacteria fixes nitrogen from the air and provides the plant with useable ammonia. This process counters the natural decay of biological material in which the amino acids are broken down into nitrates, nitrites, and ultimately, molecular nitrogen. Nitrogen is lost through leaching from the topsoil, harvesting of the crop, and through the denitrification just described. Microbiologists see potential in both plant breeding to improve photosynthesis, and in microbiology to modify Rhizobium. In the case of corn, further work needs to be done with the bacteria A. vinelandii. Researchers are working to introduce genes into the bacterium which will specify binding to the corn roots. It is felt that the nitrogen will be made available if techniques are developed to get the bacteria to bind. Additionally, corn varieties are needed which, through increased photosynthetic activity, will provide energy to the bacteria for their processes. Other applications of beneficial microorganisms include the development of bacteria which sequester iron and the use of the fungi Mycorrhizae for a variety of crops. These fungi effectively extend the root system of plants and thereby make more nutrients and water available.

The second category of microbiological techniques involves the growth of cultures from individual plant cells. From this basic technique researchers can develop mutants. Those mutants which survive certain types of stress will be adapted to that environment and used for future stock. Alternatively, individual cells are supported in bulk fermenters. The cell walls of a plant cell are removed with enzymes. The resultant cells are known as protoplasts. An example of the latter would include the production of tropical plant cells in a temperate zone fermentation tank.

Finally, genetic material can be inserted into cells. The methods of recombinant DNA are referred to as genetic engineering. Two techniques are feasible. Plant proteins could be expressed in bacteria subsequently grown in fermentation tanks. Conceivably these fermentation tanks could form a factory in which plant compounds were synthesized. Insertion of foreign genes into plant cells is the other possibility. Work in the agricultural field is being concentrated on the so-called nif (nitrogen fixing) genes. Isolation of genes using enzymes represents the most sophisticated applications of microbiology. Microbiological techniques are thus increasing the productivity of agriculture through the development of new varieties and plant/microorganism symbiosis; and potentially reducing crop wastage by developing techniques which may allow protein production in fermentation tanks.

Forecasting the time in which various techniques will be applied is becoming less an art and more a science as researchers come to better understand the recombinant DNA techniques. Within the next three years scientists feel that they will have produced animal growth hormones, vaccines for foot and mouth disease and hog diarrhea, steroids, and bacteria for miscellaneous feeds. Late in this decade it is projected that gasohol fermentation bacteria, improved yeasts, and pesticides will be developed. The more distant projections for the 1990's include techniques for cloning livestock and for nitrogen fixing capabilities of crops.

It should be noted that the projections for the near time horizon do not involve radical shifts in the production functions. The changes are, for the most part, improvements in existing techniques. By improving the characteristics of certain bacteria, fungi and yeast, the researchers will be able to increase the efficiency of a particular process. The longer range projections involve more radical shifts in the production processes and our perceptions of them. Fortunately we have a longer period of time to adjust to these 'culture shocks', both in terms of our policies and our perception of production processes.

COMPUTERS AND COMMUNICATIONS

The development of the electronic circuit known as the microchip has allowed an explosion of computer applications. Previously expensive electronic devices have dropped in price permitting the design and application of highly complex hardware. These trends may well continue as researchers continue to develop more sophistication yet inexpensive means of generating and storing electronic signals.

Computers will allow entrepreneurs at all levels of the system to have easy access to the information which we economists have assumed they have had all along. The computer in conjunction with a means of transmitting signals (telephone wires, cable television, or the full range of waves used for radio, television, and microwave transmission) permits inexpensive, immediate transmittal of information. A full range of business aplications is possible. On a global scale, Landsat images of the earth, telephone calls, and data are transmitted via satellite. In-store computers coupled with scanning devices and Universal Product Codes have allowed food retailers to collect and analyze sales data. Retail/wholesale interfaces are possible to provide automatic ordering for inventory control. Farm organization-to-market interfaces for commodities and on-farm computers will allow different marketing institutions to augment the established ones. There will be improved access from all levels of the system to data bases and financial information. Electronic shopping from home may become commonplace as well.

Improved communications systems will permit the farmer to better market his commodities. Farmers will occupy a more competitive position as they become better informed. Shaffer has proposed an electronic marketing system to operate through forward deliverable contracts. "It has generally been assumed that contracts involve direct negotiation and dispense with the market as an allocation mechanism. This is a narrow view of the market. A national market in deliverable forward contracts--using a computer and direct national input through a teleline system, with transportation calculations and brokerage built into the system--could conceivably be established. This would provide the needed coordination and reduce the stimulus for vertical integration into farming, while providing the advantages of a competitive market without the price uncertainty. However, such a market system is not likely to simply evolve. It would have to be instituted through government action".[14]

A growing number of cattle autions are being conducted via videotapes.[15] Buyers can assemble more conveniently and view many more head of cattle in a given period of time. Ranchers need not transport their cattle to stockyard of elsewhere until a deal has been struck with a buyer.

Land based sensing and monitoring devices will permit fast, accurate retrieval and storage of data. A variety of sensing and monitoring devices permit a reduction in labor costs and the collection of data which was previously unavailable. The applications include robot sensors on farm equipment, weather and soil monitoring of the farm's particular microclimate, intruder detection, and warehouse automation. These technologies are commercially available today and their use is becoming more accepted.

Remote sensing applications have improved in reliability and sophistication since the initiation of the Earth Resources Technology Satellite (ERTS) program fifteen years ago.[16] Now known as Landsat, the system is designed to provide information on cultivated crops, land and water resources, forest and range management, and other surveys applicable to the developing world. The crop information would include yield prediction, crop stress and disaster information, and cropland histories.[17] Recording information from the visible and infrared wavelengths, the satellites transmit the information to communications satellites and hence to ground stations where it is deciphered by computer. When correlated with ground and low altitude observations, this information can provide scientists with data from around the world.[18]

Computer and communications technologies have the potential for profound power shifts in the farm and food system. Where entrepreneurs are able to collect, store and analyze masses of data which aid in decision making they will have an advantage. These technologies are cost reducing. Firm size may not be a factor because a full range of computing devices is available and costs are continuing to decline.

IV. TECHNOLOGICAL CHANGES AT EACH LEVEL OF THE FARM AND FOOD SYSTEM

INPUT SUPPLIERS

Many industries produce the inputs used by agricultural producers. These industries are the suppliers of farm machinery, seeds, fertilizers and pesticides. This level of the food system is much broader and comprehensive than it may appear at first glance. Farmers use the financial and management services of a variety of institutions. Thus bankers, farm insurance groups, research organizations and private management consultants supply farm producers as well.

The competition between input suppliers has historically improved the productivity of the farm and food system. Mechanical technology has conserved the scarce labor input throughout the history of agricultural development in the United States. Improvements in the mechanized farm equipment will continue as the price of farm labor remains high. Computerized sensing devices will be standard equipment on some tractors and combines as a means of improving labor productivity. Equipment manufacturers will install sensing devices on a combine for example, which will be able to monitor machine height to the height of the crop and to follow furrows. Tractors will be able to automatically adjust the engine power to the soils being plowed to conserve fuel. Higher energy prices have encouraged machine manufacturers to experiment with alternative fuels including liquid propane, methane, and alcohol. These improvements will permit farmers to do a better job and relieve boredom on certain tasks.

Chemical inputs became widespread during the first half of this century. Fertilizers and pesticides have served an important role in the enhancement of farm yields. Continued intensive use of chemicals is unavoidable, given the system's present dependence on them. Farmers and input suppliers alike are concerned with the growing public concern over the impact of certain chemicals on the environment. Petro-chemical based products have increased in price more rapidly than other farm inputs. Prices and public concern over chemical use may have some impact on this aspect of farm production.

Biological innovations have been an important part of farm productivity increases for a century. Biological improvements raise the output per land, labor and capital unit by increasing the utilization of available plant nutrients, water and sunlight. Plant breeding and variety selection is carried out in the public and private sector with the latter group now taking responsibility for the extension activities as well. The microbiological techniques which have recently captured the attention of the media have a huge potential for increasing yields for given valued inputs. Microbiologists, in concert with plant breeders and other scientists are learning how to control the DNA of simple forms of life and the higher plants with which they have symbiotic relationships.

Input suppliers will benefit from the business applications of computers. Input suppliers will use computers to a greater extent as the cost of business computers falls. Financial records and the "paperless office" are in the not too distant future as electronic communications applications become standard business practice. Communications advances will allow them to get up to the minute information for the operation of their businesses.

The development of new farm inputs, biological, chemical, mechanical, and electronic will not significantly change the interaction between the input suppliers and the agricultural producers whom they are supplying. Farmers will continue to purchase inputs, though the mix of inputs may change. We can expect more computers and sensing devices to be purchased, different types of seed and possibly a slowing in the growth rate of chemical input purchases.

The input suppliers who are capable of making the breakthroughs in technology and patenting them will extract economic rents. One may expect a large turnover in the industries which are venturing into these risky research and development activities. Competition can be expected to be very high in these new areas.

The input suppliers who provide information and management expertise to the farmers will find that the new technologies will increase the demand for their services at first while farmers are learning to use the computers and sensing devices. "Menu driven" software and "appliance type" monitoring equipment will permit farmers to use the equipment without understanding the details. Farmers wil have an increasing ability to decide what type of expertise they need for a given problem. Consultants will need to be specialized. The factories and warehouses of input suppliers will use robotics increasingly for dangerous and repetitive tasks.

AGRICULTURAL PRODUCERS

The farm sector in America is undergoing a transition. Changes in the value of farm assets, in the size and composition of a typical farm, and in the technology applied have been significant. Present trends include a decrease in the number of mid-sized farms. Large farms, with assets in the hundreds of thousands of dollars, are continuing to grow. Small farms as well are increasing in number. These farms are able to survive because one or more family member have off-farm employment which supplements the farm income. The 'family farm' is thus not disappearing; rather, we must change our definition slightly to include those very large farms which are family controlled and incorporated and those farms which survive through the supplemental incomes of family members.

The history of technological change on U.S. farms is well documented. Mechanical technologies enabled the farmer to raise the productivity of his labor. We are well aware of the exodus of farm labor to the cities since the birth of our nation. More recently advances in chemical and biological technologies have permitted farmers to increase yields while the labor requirements have continued to drop. The use of increasing amounts of nitrogenous fertilizers along with plant varieties which are nitrogen responsive will continue. Plant breeding programs have become sophisticated and public and private funding has been repaid many times over. The scientists who work on these projects are trying to control a large number of factors critical to plant growth. Plant breeders try to improve the efficiency of nutrient uptake from the soil, the efficiency with which sunlight is absorbed and used and the plant's resistance to environmental stress. Research has been conducted as well on fertilizer and soil properties and the effectiveness of pesticides, herbicides and fungicides which most American farmers use.

The most radical change in biological technology at the farm level will be the use of genetic engineering techniques described in the above sections. Recombinant DNA techniques will give rise to new farm inputs. These inputs will involve varying degrees of change by the farmers. There will be little change in the interaction between input supplier and agricultural producer. Presumably, as patent laws permit the patenting of life forms, input suppliers will be able to capture the economic rents during the period of the patent. Farmers will continue to pay a fee for the services of the input suppliers and these costs will be passed along to the later levels of the farm and food system.

Present research is trying to enhance the photosynthetic efficiency of crop plants. The most efficient plants now capture only two to three per cent of the sunlight's energy which falls on the crop.[19] By reducing photorespiration, developing varieties which have delayed leaf senescence, or improving plant architecture, breeders should be able to increase yields.

Animal agriculture will benefit from present research on animal health including protection from infectious diseases. Potential improvements are also projected in the utilization of feeds, improved fertility, and genetic improvement. This latter breakthrough will include embryo collection and implantation. Presently this is a growing industry with 'super cows' producing fifty calves a year.[20]

Computer technology will permit the farmers to record and analyze more data than they ever dreamed possible. This data (about the weather, soil moisture, specific animals) is very important because farmers are dealing with many uncontrollable factors. State level aggregate data which farmers have used in the past are not as relevant. Farmers will be able to decide which animals need shots, what feed is needed, and which fields need irrigating given the microclimate. The relative power of the farmer will increase when he masters data collection and when the sophisticated software which he needs is developed. The decision making ability of the farmer will also increase to the point where he knows specifically when a specialist is needed; and the contracted specialist will have better access to more on-farm data. The farm is a complex system which has been run on hunches and the wisdom of experience. That will not change in some instances; however, there will be a great deal of measureable data to which the farmer will have access.

Computer and communications advances will allow farmers to market their commodities more easily and to obtain a better price. Better information at all levels of the system will provide price stability in commodity markets.

Sensing and monitoring devices will become widespread on the farm. These devices will permit weather monitoring, soil moisture monitoring, irrigation control, and sensing of intruders on farm property. The farmer's time will be saved and more detailed data will be collected. Data on the microclimate of the farm or specific fields is now collected through the impressions of experienced farmers. Soon, soil moisture and rainfall probability data will be kept and analyzed with microcomputers in order to make a decision on when to irrigate.

Robotics on field machinery will permit the farmer to do a faster, more precise job in the field. Computerized systems on board farm machinery will keep track of fuel consumed, working time and adjust the power of the engine to the task. Farmers will have more time for the management of the farm and its financial resources, an increasingly important task. The automation of several farm animal chores may be possible as well. The use of mechanical devices will continue to grow on the farm and these devices will continue to become more sophisticated.

Improvements in remote sensing techniques may allow farmers to combine that weather information with the data collected at the farm level. Remote sensing data will indicate crop projections to marketing analysts. Farmers will benefit from the improved price stability which will come with less uncertainty.

Farmers will extend the use of other technologies which have been around for several years. The efficiency of water use will be reflected by the new irrigation systems. The area of crops planted using conservation tillage is expanding in the United States. Minimum tillage and no-till systems now occupy one-fourth of the nation's cropland and conserves water, topsoil, labor and energy inputs while chemical inputs have increased.[21]

FOOD PROCESSORS

Many firms, in dozens of industries, assemble, process and manufacture food. Foods commodities travel from the farm gate to the distribution centers under the direction of these industries. Processors are concerned with the timely preparation of a product in the form desired by the consumer: good quality, packaged well, at an acceptable price.

Technological innovation in these industries is in response to a variety of economic forces as well as a desire to develop new products. The economic forces include rising energy costs, water shortages, and a need to increase shelf life. Energy price increases have encouraged processing technologies which conserve energy. Many areas of the country are experiencing acute competition for water resources and those food processors which use quantities of water are trying to reduce their consumption. Shelf life of the products is important and processors are researching a means of improving product performance.

Food preservation is carried out in order to reduce food loss during processing and transportation and to extend the shelf life of a product. Preservation is done by either removing, destroying of suppressing the microorganisms which cause food decay. Filtration or centrifuging are appropriate for microorganism removal in certain foods. Heating and radiation are used to destroy microorganisms. Suppression can be obtained by either cooling, freezing, reducing water content, freeze drying or by introducing food additives which slow the rate of spoilage. The use of chemical food additives to suppress the growth of microorganisms has come under attack from consumer interest groups. The industry is investigating other ways of preserving foods which are less subject to attack.

Different ways of heating and radiating food are being explored to destroy microorganisms. Aseptic packaging refers to the packaging of food under very hot conditions in order to kill microorganisms. The process involves 300 degree heating (Fahrenheit) for three seconds. The resulting product will cost less to transport (refrigeration will not be necessary) and will have a longer shelf life. Some taste changes may inhibit public acceptance as in the case of sterilized milk.[22] The quality of the food can be better, however, and nutrient levels are kept high. Processors are interested in this technology because little energy is used during the brief heating period. Milk remains a promising food for the introduction of this technology despite the present drawbacks.

Irradiation technology has been studied in the past but it is regulated and irradiated must be proven wholesome before marketed. Irradiation can be used to inhibit the sprouting of potatoes, or to kill certain microorganisms. Other applications include large scale irradiation of grains and disinfestation of fruits to kill insects. The use of radiation extends shelf life, indefinitely if high levels of radiation are used. Some flavor changes occur therefore its greatest drawback may be consumer acceptance.[23]

Microwaves can be used by the processors to pasteurize and precook food. The technology is known at the home level and may get increased use by processors to save energy. Marketing strategies are needed to introduce new products to the public which have been precooked. The growing use of microwave ovens at the home level may allow the introduction of meals which are precooked by microwave and then reheated at home in seconds.

Food fabrication (also known as "food engineering" or "food synthesizing") uses food ingredients rather than actually synthesizing food from chemicals. A well known example of a fabricated food is vegetable protein used as a meat extender. Soybean oil is commonly used in dairy products and soy protein as an ingredient in fabricated meat. In many cases, foods which would otherwise be wasted are combined to make products which are palatable and nutritious.

Consumer acceptance of certain fabricated food ingredients may be difficult to overcome. Labeling is an important issue because proper identification must be weighed against efforts to gain consumer acceptance.[24]

Microorganisms have been used for a long time in the production of cheese, bread, wine and many other foods. Some modification of these processes has occured as processors have been able to identify the specific organisms. Further research is being conducted to improve the quality and precision of the fermentation process. One improvement is the development of continuous techniques to replace the batch techniques which are now used. Genetic engineering of these organisms may allow more efficient fermentation. Materials now considered waste can be converted to edible protein. The use of vegetable pulp and peelings and animal byproducts as food ingredients may become widespread if the technical problems are overcome. Waste conversion is constrained however by consumer acceptance, labeling controversies and approval by regulatory agencies.[25] There is a greater chance of acceptance if these products are used as animal feeds.

The retort pouch is a multilayered container made of plastics and metals. The pouch has potential for energy savings in both processing and transportation due to shorter cooking times and lower weight respectively. Food is placed in the pouch and sealed. The pouch remains intact throughout processing, transportation, storage, and reheating.[26] Labor requirements are reduced in an institutional setting where the pouch has the best potential. Presently the filling speeds are slow for many pouch sizes. Institutional uses are the most promising because the filling speeds are comparable for the larger containers and because the hired personel can be easily trained in the reheating of the pouch.

Recycling has potential in terms of energy savings, however the institutional and sanitation problems are great. In other packaging innovations, more plastics will be used in combination with paper and metal. Less corrogated cardboard containers will be used. These changes will be in response to changes in energy costs and the cost of certain materials.

Mechanical deboning of meat involves crushing the carcass and bones and then separating the bones mechanically. Tha chance of bacteria contamination is greater and bits of bone often remain in the meat, therefore this technology has met with some resistance.[27] If instituted on a large scale, the effective supply of meat products would increase, thereby lowering demand at the farm or ranch level.

New instrumentation will become available for the detection of ingredients in foods. Food safety is a concern in many areas of processing and new instruments would allow easy detection of harmful substances. They could possibly remove some of the unknowns in food fabrication and thus help with consumer acceptance.[28]

Butchering operations can benefit from the use of microchips to keep track of the carcass in. This will permit tracing of contaminated carcasses.

Mechanical devices, coupled with computers will appear for a variety of food sorting, grading and processing operations. Robotics is growing in sophistication as the cost of computer components falls and the sensing devices become more capable. Sorting of fruit by color is possible. Processors will take advantage of automation where it reduces costs.

Transportation costs are reduced by processors by reducing the weight and size of the product and its package. Dehydrated products are lighter and have a longer shelf life. New packages such as the retort pouch are lighter than the cans which they will replace.

Solar energy use in processing may be used for the dehydration of foods, and preheating of washing water to save energy. Certain industries now use nonrenewable resources for these operations.

Conservation technologies are being developed which will permit the use of waste energy. Cogeneration involves the use of low energy waste heat from an energy generating plant which uses high energy steam. Many food processing operations require an input of hot water which could be provided using the waste heat of existing industrial plants.

Business computer applications will become routine for the processing industries. Firms will experience increases in productivity throughout the farm and food system as offices and management acquire reliable, up to the minute data and analyses.

Processors and manufacturers will focus on new product development using some of these new technologies. Marketing efforts will emphasize the distinct characteristics of segmented audiences. Specialized media such as magazines, radio, and cable television have relatively narrow audiences which will be targeted by the manufacturers.[29] Processors and manufacturers are active in the introduction of new products.

FOOD DISTRIBUTORS

Food distribution is composed of wholesaling, retailing and associated transportaion functions. Wholesaling operations will be characterized by the changes in warehouse automation and by their electronic interfaces with retailers. Retailers will share this interface, use more electronic checkout devices (scanners) and establish ordering systems which will minimize the disassembly and reassembly of products. In-store computer systems will permit on-site analysis of retail data. The retailing function will take on new dimensions as in-home ordering occurs for both retail food and complete meal delivery to the homes. Transportation functions will be better coordinated through improved communications. Computer systems will allow the tracking of containers to permit better sanitation. Standardized containers will move more easily from one form of transportation to another.[30]

Industrial robots which have been introduced into a few industries have a potential for automating the warehouse. Computerized systems in conjunction with standardized shipping containers would raise productivity. This potential may be slow to come however because of the large number of units necessary to make such a system profitable. Increased concentration in wholesaling and retailing and implementaton of more automation would reduce the need for labor. The associated policy issues and high investment costs may prevent wholesalers from using these technologies in the near future.[31]

An electronic interface between the retailers and wholesalers would permit automatic ordering to replenish store inventories. Retail store computers will gather the information provided by the introduction of the Universal Product Codes (UPCs).

Electronic checkout will have the greatest impact in the next ten years. The UPC checkout enables retailers to collect sales data specific to their 'micromarket retailing area'. Retailers will, for the first time, have the data necessary to optimize the use of their shelf space and inventories and improve labor scheduling and sales analysis. The relationship between retailers and wholesalers, and between retailers and food manufacturers, changes significantly upon adoption of the system. Retailers are able to decide for themselves exactly what sells and what does not in their store.

Though the technology came into use nine years ago, only fifteen percent of retail sales are 'checked out' with Universal Product Codes. Manufacturers and wholesalers want to purchase this data from firms which buy it from the retailer and analyze it. Whether the larger or smaller retailers benefit more from the new technology is as yet unknown. Large retail chains may encounter implementation problems which would be avoided in a smaller store.

Computer systems in retail stores will involve more than the analysis of sales data. The control of physical facilities such as heating, lighting, refrigeration will be possible by 1985.*

Electronic shopping will be possible with the widespread use of in-home computers or specialized hardware. Consumers will check prices and order food from their homes. Using a television screen or monitor the consumer will be able to look at an image of the product before ordering it. It is difficult to say when this technology would be implemented. The savings are potentially very high. Energy and labor savings would occur because handling would be reduced and transportation of the food would be more efficient. Direct electronic purchase from the warehouse would occur. Delivery vans would bring the order to the door. Potentially this would eliminate the retailing function as we know it for everyday items. Specialty shops will flourish because people will continue to shop as a form of entertainment. An electronic shopping system may first be implemented in villages for the elderly or inner cities where access to food is a problem.

Recycling is not a new technology per se; rather it is a way of conserving resources. The systems are not set up to have a return flow of containers and the labor costs are high. More recycling will occur where it is legislated. Research is continuing on the design of packages which can be safely burned for energy production.

Better coordination through standardization of shipping containers and improved communications will permit efficient food transportation. Standardized palates and crates will be used throughout the system. Intermodal containers will permit the transfer of products from one means of transportation to another with little problem.

Food sanitation in transportation systems will improve and thus food spoilage and wastage will be reduced. Freight cars will be constucted to be more resistant to contamination and specific cars will designated for food transport.[33] The technology exists as well for computerized tracking of the railcars to avoid using a car for food which has been carrying a toxin. The important problem faced by the rail industry is not lack of new technologies or potential applications. The rail system lacks the funds to upgrade their cars and tracking systems.

CONSUMERS

Several new technologies are projected to have an impact on the home. These include changes in radio and televion broadcasting, cable transmision, video players, and microcomputers. Technologies which change the way that consumers receive and send information may have far-reaching sociological impacts which are beyond the scope of this paper. Toffler refers to some of these changes in his book "The Third Wave."[34] One of his projections is the growing importance which the home will have as we expand the communications frontiers. Toffler envisions a growth of cottage industries conducted from the home via computer and cable. While much of these projections are speculative, analysis of the past few years coupled with a knowledge of the new technologies available to the home will allow us to form a good picture of the coming ten to fifteen years.

Radio and television exploded into American society in the 1920's and 1950's respectively. Now as we enter the latter part of the twentieth century dozens of new technologies, each having a small impact, collectively are revolutionizing the ways in which we receive and transmit information. Audio and video hardware and associatred software have developed markedly in the past decade. Cable television is now used in twenty-five percent of American homes and this figure is expected to nearly double in the next four years.[35] With the availability of many more channels, the audiences and programming will be more focused as radio is now. 'Narrowcast' programming and advertising will aim at specific audiences.

Other broadcast technologies include multipoint distribution service, low power stations, VHF drop-ins, direct broadcast satelitte systems, high resolution TV, subscription TV, and videotext.[36] The purpose of many of these technologies is to increase the number of possible programs available to the consumer or to improve the existing images. In many cases the technologies present new regulatory and licensing problems to the government. In addition to the economic competition there are inherent physical problems where one technology may interfere with another. These externalities are forcing those who make the laws to deal with a variety of problems.

Video cassette recorders and videodisc players, whose use became widespread starting in 1979, allow consumers to record programs and view them at their convenience. Additionally, consumers can purchase prerecorded movies or make their own.

Videotext and the growing use of in-home microcomputers allow consumers increased access to instantly updateable information such as schedules, fares, and retail prices. Using the television set or a monitor more appropriate to text viewing, consumers are able to scan information quickly to find what they wish.

In addition to games, educational software, and household finances; microcomputers will be used with communications packages to order goods direct from manufacturers and warehouses. Food will be ordered, charged to an account, and delivered to the home. Economies of scale will allow a greater choice in the selection of commodities, a reduction in purchasing time, competitive prices associated with better information, and reduced travel costs.

The use of microwave ovens will continue to expand. More food will be marketed specifically for the microwave. Energy costs for cooking will be less when prepared in bulk at the processor level before reheating quickly by the consumer.

Presently, there is an inadequate system to permit used containers and packages to flow back to the manufacturer. Institutional problems are more critical than the technical problems. Future containers may be all burnable for use in energy production. We need to make garbage valuable so that it will pay someone to pick it up and burn it.

Future credit cards will contain a microchip which will register the users bank balance and hence permit the seller to confirm a purchase. The 'smart card' will also keep track of many separate accounts and credit and debit them with each transaction. Banking by phone will be permitted as well with the microchip allowing the user to pay bills and balance their checking account.

V. CONCLUSIONS

The technological frontiers noted above give an indication of how the way we interact with the physical world is evolving. Social arrangements or 'rules of the game' change in response to these technologies. The design of new institutional arrangements in turn feeds back on the rate and kinds of technological innovation. Ours is a highly interdependent world, both within the categories outlined above and between them.

Farm and food policy is concerned with the role of the government in assuring that the system performs as citizens of our democratic political economy wish. The purpose of this paper has not been to describe that political process nor to prescribe solutions to the inevitable conflicts which occur when people's preferences differ. Rather, the paper has presented some of the important technological changes and highlighted some of the foreseeable policy problems.

Within this decade a variety of technological changes will occur. Included will be both some new discoveries in computer technology and microbiology, and the application of technologies which are well understood now. In the case of certain changes there is a lag due to problems in innovation. The majority of firms are hesitant to try risky ventures. Learning a new technique can take time, and firms are faced very real fixed assets. The use of electronic checkout technology provides a clear example: the technology was first introduced in 1973, however, the nine percent of retail stores now using it are simply the first to overcome the barriers of retraining and reinvestment. This decade will see the adoption of electronic checkout by the majority of retailers. Several technologies are now in use by a few firms, and the applications will accelerate now that a trial period has passed.

Technologies which reduce costs will permit the innovators to capture economic rents while other firms have yet to adopt a technology. Cost reduction is no assurance that the benefits will be passed on to consumers however. Technologies which rely on large scale economies for implementation will increase concentration in the industry. Government's role in this case will be to design institutions which will regulate the firms to prevent extraordinary profits. In certain cases this may simply involve a institution which provides consumer access to price information. Advances in communications will continue to reduce the transaction costs which hamper perfect competition in the real world.

The role of government in allocating scarce research dollars is increasingly important as the scale of research efforts increases. Private financing is possible where the science is well understood and where potential benefits can be captured within several years. Publicly supported research continues to be important for basic research and in those areas where the risk is high. Where publicly supported research benefits one group over another, the difficult equity issues must be addressed.[37]

The role that the economist can play with respect to new technologies is an important one. Certainly, estimates of the impact of new technologies, no matter how crude and approximate, are useful. Information gathered on both the macro and micro levels will enable the economist to estimate the economic rents accruing to the entrepreneurs and the benefit accruing to society. Measurement of the economic surplus and other economic tools still have problems because they are partial analyses. As long as the analyst can highlight the impact of a technology, including the shortcomings of its measurement, then some useful information has been provided to the public. The crucial distributive impacts of technological change can be measured in gross terms by the benefit-cost specialist. This information is useful to politicians who make the final decisions on government supported research efforts and on regulations which have an impact on the rate of technological innovation.

Industry level studies permit policy makers to understand the impact of a regulation on the structure and performance of the industry. Economists who study an industry over a long period of time can integrate the necessarily limited data which may be collected for any one study. Their analyses serve as the basis of future regulatory decisions. Other economists may choose to specialize in a particular area of policy such as worker safety regulation or water quality regulation. Their work will cut across the boundaries of industries to give the policy makers a different perspective.

Economists can assist the firms which comprise the farm and food system as well. Decisions about capital investments often lack adequate information. Arguments about the distribution of rights and privileges aside, using economic/engineering studies, the economist can determine the optimun scale of operation and the point of allocative efficiency.

To say that there is a great deal which can be done by the economist to study technological change and the farm and food system would be an understatement. Both public and private decision makers can use the analyses which the economist can provide after studying a particular technological change.

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