each sector's requirements for labor of different qualifications. A set of dynamic input-output equations specifies the relations among the four matrices in any year and also relates the production of capital goods in one year to their subsequent use. The computational approach developed for the World Model has been adapted for this model.

The Present Situation

The extension of the traditional curve-fitting methodology to its upper limits is represented by the model of the world economy used in Project LINK (*11*). This large-scale economic model links together an increasing number of large and small, annual and quarterly, and national econometric models of the Keynesian type by means of additional equations describing international trade in four aggregative categories of goods.

Today, standard econometric procedures based on aggregation and statistical inference still dominate the field of economic research. However, the input-output approach, designed to make the fullest possible direct use of detailed factual information, is now being employed in most of the major areas of economic inquiry. Compilation of at least small national and regional input-output tables is being carried on in all developed and most developing countries. In Norway, for instance, and particularly in Japan, systematic compilation of such a database is considered to be one of the principal tasks of the official statistical organizations.

As the demand for more realistic modeling increases, detailed engineering and other types of technical information are beginning to supplement and, in some instances, even to replace the more conventional sources, such as census figures and accounting records, in the compilation of input-output information. The cost of constructing and maintaining the comprehensive database that would be needed to carry on an analysis of the operations of a modern economy useful for public and private decision-making is bound to be high—much higher than the amounts now spent by official statistical agencies such as the U.S. Bureau of the Census. At present, however, the collection of statistics by the government seems to have been gradually deteriorating. Partly as a result of this, corporate data gathering is on the increase. Privately collected information tends to be fragmentary and, because of its proprietary character, cannot be made available (except at prohibitive cost) for scientific use. Economists may be facing the unenviable prospect of entering the information age without sufficient information.

As recently as thirty years ago, effective application of the modern model-building approach to the study of large economic systems was restricted by the absence of adequate computing facilities. Further progress in the field will be limited by the lack of requisite factual information. In the long run, economics as an empirical science will be able to take full advantage of the immense data processing capabilities of modern computers only by modeling the economic system in very great detail and by creating the large, comprehensive, and at the same time detailed database required for the implementation of such large models.

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Computers in Production Agriculture

Donald A. Holt

Computers are beginning to play important roles in production agriculture, just as they do now in many other industries. In general, they are being used in data capture and processing, automatic control, and as decision aids. Eventually, through a combination of communication, monitoring, analysis, simulation, expert systems, and automatic control, computers will make large, efficient farm operations even more productive and efficient than they are now. The spectrum of possible benefits is projected in the following scenario.

Scenario

It is a clear June morning somewhere in the midwest. During the night, the farm computer automatically dialed several local and national databases to obtain information on current fertilizer, seed, fuel, and pesticide supplies and prices; weather; markets; insect and disease predictions; and buyer offers. Now it turns on the radio, which gently awakens farmer Bob with music. After a few minutes, information gathered and processed by the computer during the night appears on the bedroom monitor.

Sensors in nose rings, ear tags, and implanted devices have been scanned to assess the physiological condition of the farm's animals. Confined sows and cows coming into estrus have been identified automatically by sensors monitoring mounting activity and vaginal secretions, and they have been scheduled for receipt of frozen embryos.

The automatic feed grinders and mix-

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ers functioned satisfactorily during the night. All animals were automatically fed and watered, the quantities of feed distributed recorded, and the amounts consumed by each animal estimated and registered. Remaining levels of grain, protein sources, and feed additives in bins and tanks were measured, and replenishment orders were automatically placed with local suppliers through the computer network. The ration-balancing program, by using data on nutrient concentrations in purchased and home-grown feeds, has recomputed optimum, least-cost rations for each class of livestock and reset the automatic feed processing and mixing equipment to produce these rations.

Son Bill is already monitoring the milking of the 200-cow herd. As the cows enter the milking stalls, which they do several times daily, milking robots sense each cow's position and slip on the milker. Each electronic ear tag has been automatically identified by the computer. A specified quantity of grain, protein, supplement, and vitamin and mineral mix, tailored by the computer to that cow's production potential, drops into the feeding cup. The computer monitors the quantity and butterfat content of milk flowing from each quarter of the cow's udder and measures conductivity to detect infections.

The monitor shows that each of the PABA's (pituitary-accentuated beef animals) visited its electronic feedgate at least once during the night and that the huge, docile beasts received their required supply of roughage. Environmental conditions in all farm buildings and facilities, including the farmhouse, were monitored continuously during the night and automatically checked against acceptable standards and schedules. Actions to illuminate, darken, heat, cool, dry, humidify, ventilate, and move animal wastes to digesters were initiated by computer as necessary, and the functions of all mechanical devices were checked regularly.

The motor driving a small auger in the feed-mixing facility is drawing excessive starting current. This problem was communicated automatically through the computer network to the local electrician holding the feed system maintenance contract. Having received this information by telemetry on her truck computer, she is at work replacing the unitized segment of the auger containing the dry bearing that caused the problem. The microwave scan of remotely controlled mechanical devices also shows that a fuel cell–powered weeding robot is on its auxiliary ethanol tank and will soon be coming to the shop area for refueling.

The computer has been scanning by telemetry a number of miniature portable weather stations placed in the fields. It scans these every 15 minutes, computes heat unit and solar radiation accumulations and plant-available moisture, and summarizes and stores these data, which are forwarded automatically to state, federal, and private weather agencies for further processing. The unit in the strawberry field that monitors frost damage potential by differential thermal analysis has been automatically shut down and needs to be retrieved for use in the orchards, where it will alert the farmer and activate sprinklers when frost threatens in the fall.

The computer uses weather and soil moisture data, plus short- and long-range weather forecast information from the network, in several simulators to predict the status of farm crops and pests. On this particular day, it anticipates low soil moisture in sands near the river, has actuated the pivot irrigation system in that field, and is monitoring and controlling the pump, methane-powered engine, boom alignment and travel, corner unit, and delivery rate. One simulator has identified this day as the optimum time, in terms of weather conditions and plant growth stage, for dealing with foxtail infestation in the soybean field south of the road by treating it with a photoactivated herbicide. The herbicide will be applied in extremely small quantities by high-clearance ground equipment, with precise microprocessor control and monitoring of steering, ground speed, pump pressure, carrier volume, nozzle performance, and application rate of the active ingredient. Analyzing images from infrared scanners, the microprocessor will shut off specific nozzles as they pass over noninfested areas. When the morning sun of the following day activates the herbicide, the invading foxtail will be eliminated.

One simulator predicts an infestation of European corn borer in the early-planted corn. After breakfast Bob enters the field, carrying a small electronic device consisting of a 7 by 10 centimeter video screen and a small keyboard. Using the eraser end of his pencil, he types "IPM" (Integrated Pest Management). This command establishes microwave communication with the farm computer, which accesses an IPM expert system on a random access optical disk in the county cooperative extension office. The program leads Bob through identification, diagnostic, and decision steps by means of voice, text, and color pictures. When the predicted degree of infestation has been verified by sampling, a least-cost, environmentally safe, biological control procedure is prescribed.

At about 10 a.m. the farmer takes the combine to harvest the early maturing variety of seed wheat. As the combine moves into the field he activates the microprocessor, which positions and maintains the header at optimum height; adjusts reel height and speed; optimizes concave clearance, cylinder and fan speed, straw walker movement, and air volume; and monitors seed moisture concentration and seed loss. After the machine has proceeded several yards the combine computer alerts the farmer that additional grain will be saved if the operation is halted until seed moisture drops 2 or 3 more percent. The farmer uses that time to check the moisture-monitoring equipment of the computerized bin drying system in which the seed wheat will be gently dried to an optimum moisture concentration for safe storage and high germination rate.

Meanwhile, back at the house, Bob's spouse and business partner, Claire, is analyzing data on household and other expenditures and studying the updated accounts and detailed financial analyses provided by computer. Through the network she authorizes debits against various accounts and orders supplies, parts, and household goods. She employs their custom-designed master farm management program, an enormously complex combination of simulators, databases, and artificial intelligence, to make decisions on livestock marketing schedules, forward pricing of grain, and compliance

Summary. Modern production agriculture in the United States is becoming so complex and sophisticated that computers may soon be an essential tool of successful farm operation and management. Farmers are vigorously seeking information on relevant computer technology and using it as rapidly as economics and availability permit. Their demand for this technology is, however, price-sensitive under current economic conditions. The agricultural research and development system has a long way to go to provide the large integrated software and hardware packages—including simulators and expert systems interfaced with monitoring and control devices—needed to help American farmers retain their competitive edge.

Table 1. Selected characteristics of farms by volume of sales in 1981 (*1*).

Sales (dollars)	Number of farms	Percentage of all farms	Percentage of all sales	Income, excluding households (dollars per farm)			Costs [parity ratio to cover all costs (1910 to 1914 = 100)] (dollars)
				Net from farming	Off-farm sources	Total	
≥200,000 (large farms)	112,000	4.6	49.3	176,063	17,125	193,188	54
40,000 to 199,999 (mid-sized farms)	582,000	23.9	38.1	11,266	9,569	20,835	77
<40,000 (small farms)	1,742,000	71.5	12.6	−663	18,279	17,616	132

with government programs. Included in the master farm program is a highly automated accounting system providing for double-entry cost accounting, complete depreciation schedules, hired labor records and payroll management, and automatic generation of all necessary tax records and forms for their family corporation.

The fruit-marketing expert system has identified a buyer offering an acceptable price for the two trailer loads of apples stored in the local controlled atmosphere (high carbon dioxide) facility and is seeking Claire's authorization to complete the transaction. The risk management expert system, drawing on weather records, long-range weather forecasts, large-area production forecasts generated by government simulation models, satellite imagery, and current and predicted market conditions, recommends that additional crop insurance be purchased for the portion of the corn crop on the upland areas of the farm.

The cash flow analysis predicts a July shortfall of $50,000. This information has been communicated to the local farm credit center, accompanied by the required net worth and cash flow statements. During the night the computer automatically transferred last week's updated record of farm accounts to the state office of the Farm Business Farm Management Service. A report received from the system shows that this farm's feed efficiency, livestock productivity, and net returns to livestock operations are well above the average for similar operations. Efficiency of fertilizer use for corn, however, is only average, suggesting that the knowledge base of the soil fertility expert system may not be complete enough for the unique claypan soils on the farm's southern half.

Today, daughter Rosalind, an agriculture student, will spend 2 hours in the field with the small video device, identifying weeds and studying weed ecology, guided interactively by the nation's leading weed scientist. The knowledge, appearance, and personality of the teacher are captured on the optical disk by a unique programming approach that makes interaction as realistic as if the teacher were present. At intervals determined by her progress, she will spend periods of 2 days to 2 months at a college campus for oral examinations, laboratory experience, counseling, seminars, and simulator training.

Sometime during the next night, the farm computer automatically connects to the supercomputer and mass storage devices at the state university for a weekly check of all farm software against the constantly refined and updated programs residing in the university's master files.

When?

The technology already exists to do many of the things described in the foregoing scenario. Some of the computer applications are commercially available, including most of the dairy automation equipment, some of the equipment-monitoring features, and most of the accounting and inventory management software. Robotics and large integrated farm management and control software packages, including expert systems, remain to be developed. Texas A&M University is developing a highly computerized, 2000-acre research and demonstration farm that will have many of the features described in the scenario.

In the United States there are relatively few large farms, somewhat more medium-sized farms, and many small farms (Table 1) (*1*). Large and medium-sized farms account for most of the farm products produced. Large farms benefit from economies of scale and have much lower costs per unit produced than medium or small farms. The average small farmer loses money farming but supplements income with other employment. Trends indicate that the number of large and small farms will increase and that the number of medium-sized farms will decrease.

Information is becoming increasingly important. World commodity prices fluctuate widely because of the vagaries of weather and politics. Technological and political developments at home and abroad are dramatically increasing the number of management options. In the highly competitive environment of American agriculture in the future, those who survive will be those who are able to acquire the most accurate and best organized information and use it most effectively.

The farmer who produces less than $20,000 in cash sales of agricultural products annually and already subsidizes his farm operation with other employment is not likely to spend much on agricultural computer systems. Some Illinois farm computer hardware and software vendors expect relatively little business from farms of less than 200 acres. Average cash sales on such farms in Illinois were about $50,000 in 1982, according to the 1982 agricultural census. About half of Illinois' 100,000 farms had cash sales greater than this, but only about 30 percent of the nation's 2.4 million farms exceeded this level of sales. My communications with farm press people who monitor the farm computer situation suggest that about 8 percent of farmers now own personal computers they are using for farm business, with another 2 or 3 percent having direct access to such computers. This is up from about 1 percent in 1981 and 6 percent in late 1983. Certain specific enterprises have been rapidly computerized. For example, most large-scale dairy farmers participate in computerized record keeping and 25 percent of Mississippi's catfish farmers use computers for management.

As the cost of computer hardware and software decreases, agricultural information networks expand, and more databases become accessible to farmers, the cost of information is decreasing relative to the costs of raw material and energy inputs, thus favoring investment in information-gathering and -processing equipment. In general, large farmers will make the most effective and efficient use of computer technology, just as they do of other technology, because they will be able to spread costs over more units of production. Large farmers are more likely to be able to buy or gain access to high-capacity computers and large integrated software packages—some custom-developed for specific types of farms. It will probably be more economical for many medium and most small farmers to make use of shared systems and smaller "canned" software items. By participating in a local shared system, the mid-sized farmer will be able to obtain management information that is almost as good as that enjoyed by the large farmer. Just as in the past, when small farmers gained economies of scale by participating in threshing rings and sharing labor and equipment to put up hay and silage, butcher meat, and harvest other grain crops, today's medium-sized farmer will have to cooperate in order to survive and compete.

It follows that relatively few farms will be in the market for expensive customized hardware and software systems or will hire consultants with such systems. Relatively many farms will require less expensive equipment, adequate to allow them to access shared databases, software packages, and other computer services. The number of farmers is small relative to the total population; thus, farmers represent a small proportion of the total market for computer equipment. On the other hand, farm-related business is big business, accounting for 20 percent of the gross national product.

Farmers need computer systems that are at least as complex as those used in any other business. They deal with some of the most complex risk management problems in business because their operations depend not only on economic variables but also on physical and biological variables, some of which are uncontrollable and difficult to predict. They need unusually sophisticated cost accounting and cash flow analytic capabilities, simulators of various physical and biological systems, ability to capture and integrate tremendous amounts of data, and expert systems that will extract the most useful and appropriate information from databases and simulators.

Agricultural Software and Systems

The private sector is a major supplier of computer hardware and software for use on farms. The October 1984 *Illinois Agricultural Software Source Guide* (*2*) provides a useful perspective on this component of agricultural computerization. The guide lists 64 firms supplying agricultural software in Illinois. Of these, 15 are vendors (firms that develop, test, distribute, and market agricultural software) who are also dealers, one is a marketing representative who does not deal directly with farmers, and the rest are dealers. Eight general software categories, including accounting, crops, beef, dairy, poultry, swine, marketing, and more narrowly focused decision aids, are represented. Almost all the firms provide software in more than half of these categories. Virtually all provide accounting and crops software. Thirty brands of computer hardware are marketed by these firms. Thirty of the firms support IBM or IBM-compatible hardware, 27 support Apple, and 13, Tandy. CPC/M and MS/DOS are the most common operating systems supported.

Large computer firms are showing increased interest in agriculture. For example, Control Data Corporation (CDC) is developing a network of agricultural franchises in several states called ADVANTAGE. Originally aimed at small farmers but now broadening, these franchises offer, among other things, computer-assisted courses in various agricultural subjects utilizing CDC's well-known PLATO system.

Farmers with appropriate equipment have access to many different public systems. The largest and best known of these is AGNET, which originated at the University of Nebraska in 1975 and is centered on a mainframe computer in Lincoln. From the start, the developers of AGNET concentrated on making agricultural software available to anyone who wanted to access the system. AGNET has several thousand clients in 46 states, 6 Canadian provinces, 7 other foreign countries, 36 land-grant universities, 15 state departments of agriculture, and the U.S. Department of Agriculture (USDA). AGNET software is owned by individual authors, mostly university specialists. Users are on-line to the main computer when using the software.

A major state network serving farmers is Purdue University's FACTS, a network linking county extension agents with on-campus agricultural computers. FACTS, developed with a $5 million grant from the Kellogg Foundation, maintains dedicated lines to county agents' offices. Recently, FACTS began supporting a bulletin board system, providing individual access to messages, databases, and interactive software. Michigan State University's COMNET, originally implemented as a remotely accessed, interactive computer system, is evolving toward distributed processing, with the central computer facilitating text file interchange and electronic mail. Other states and the federal government are developing similar systems. IMPACT, a system being developed by the University of California, Davis, is focused on integrated pest management, but within that context provides many different kinds of management-oriented software. Oregon's AGMAN will provide a broad range of management-oriented software. Several other state institutions are encouraging the use of microcomputers in county extension offices and are providing software on floppy disks for county agents and others who may wish to purchase it. In general, the fees for this software cover only part of the cost of producing and distributing it.

Several agricultural databases are accessible to farmers and others with proper computer equipment. Purdue University, with USDA, Environmental Protection Agency, and other support, is developing a national pesticide information retrieval system to provide detailed information on safety precautions, permissible uses, and rates and methods of application of various pesticides. The University of Hawaii is developing a natural resource information system from which users may obtain information on appropriate land use, erosion potentials, irrigation needs, and other resource information for any parcel of land in the Hawaiian Islands. Several private firms maintain frequently updated databases, mostly for price data retrieval, that can be automatically accessed by farm computers. Such data can then be used in commodity-charting software and other decision aids.

The amount of agricultural software available for farm use is increasing rapidly. Over 200 programs covering many diverse areas are available on AGNET. Purdue's FACTS system provides over 70 different items of software. The Mississippi Cooperative Extension Service lists 32 pieces of management software. (Of course, state universities provide software most appropriate for the locality—for example, Colorado State University provides several large integrated packages of software for managing beef cattle operations.) Strain and Simmons (*3*) have compiled an updated inventory of agricultural software, including over 700 agricultural computer programs intended for farmer use.

The most useful software items provided by the land-grant institutions for farmers are those that allow the farmer to input information specific to his farm and receive specific recommendations or analyses. Examples are the New Jersey

Peach Pricing Program (*4*) and the Arkansas Rice Management Program (*5*). The 8000-user Illinois Farm Business Farm Management Service, a user-supported organization working closely with the University of Illinois, and Michigan's Tellplan provide computerized accounting services for farmers. In the latter two situations, most cooperators enter data on forms by hand. The forms are sent to or gathered by the accounting service, keyed into databases, and computerized. The analyses, including monthly or even more frequent cash-flow and net-worth statements and automatic production of income tax forms, are provided in written form or in computer dial-up format.

Very few farmers have access to detailed whole-farm simulators that would allow them to practice or experiment with management alternatives without incurring the cost of actually conducting the operation. A simulator of this type is being developed by Southern Regional Research Committee 156 (*6*). When complete, it will be a large and complex program for assessing alternative strategies for beef production under various land, energy, and economic constraints. The effort evolved from BEEF, a model developed at the University of Kentucky with National Science Foundation support and with input by North Central Regional Research Committee 114 on beef-forage systems. The USDA recently launched three regional research, development, and technology transfer efforts, called conservation production systems, with the goal of producing integrated decision-aid software packages to help farmers choose and manage systems that are both profitable and soil-conserving. The Soil Conservation Service (SCS) will use SOILEC, developed at the University of Illinois, for this purpose. EPIC, developed by the USDA Agricultural Research Service (USDA-ARS), SCS, and Economic Research Service to predict erosion effects on a multiyear, national basis, is being scaled down to focus on individual watersheds, farms, and fields.

The Kansas Cooperative Extension Service, financed in part by a Kellogg Foundation grant, is producing farm management software packages organized around specific enterprises (*7*). Nearing completion is CORNpro, a corn management decision-aid and user tutorial package consisting of modules for cost versus return, fertility, seedbed preparation, hybrid selection, soil insect control, weed control, irrigation, and marketing. A complex "shell" program links the modules so that a user sees the effect of one decision on another. The "bottom line" of any specific decision is predicted. Modules for other enterprises can be packaged in the same shell. Cotton and Insect Management (CIM) is an enterprise model developed by state and USDA scientists in Mississippi, Florida, Wisconsin, and Illinois (*8*). Such packages, aggregated to whole-farm scale, automatically collecting internally and externally generated data, and with mechanisms for seeking optimum solutions, constitute the wave of the future in agricultural software.

Cotton and Insect Management is one spinoff of almost two decades of effort by USDA-ARS scientists, working with colleagues at Mississippi State University and other institutions, who led in the development of crop growth simulation models, beginning with the cotton model SIMCOT, developed in the late 1960's and early 1970's. This model and its descendents, including, among others, the cotton model GOSSYM and soybean model GLYSIM, are used in many domestic and foreign situations, now primarily as research tools, but with great potential as management tools. Other well-known crop simulation models include SOYMOD, a soybean model developed at the Ohio Agricultural Research and Development Center; SOYGRO, developed primarily at the University of Florida; CERES-Wheat, a model developed by USDA-ARS at Temple, Texas; SIMED and ALSIM, alfalfa models developed at Purdue and Cornell universities, respectively; and SORGF and CORNF (plus their later microcomputer versions, SORGAP and CORNAP), developed by Texas A&M researchers at Temple, Texas. Kickert (*9*) lists these and almost 300 other published computer models in the environmental biological sciences, many of which would be useful in farm and forest management software packages. Very few simulation models, however, are currently widely used directly by farmers as management tools. SOYMOD, GOSSYM, and SOYGRO are nearing this stage of development.

The technology of expert systems is just beginning to be applied in agriculture. An expert system for diagnosing soybean disease, developed by plant pathologists and computer scientists at the University of Illinois (*10*), may be the first application of such technology in agriculture. With this software a lay person, untrained as a plant pathologist, can identify symptoms of soybean diseases and obtain a diagnosis. In an initial test the expert system outperformed human experts, registering 100 percent accuracy to their 96 percent. Purdue University is conducting a year-long, federally financed evaluation of the future role of artificial intelligence in agriculture.

As yet, there is no widely used system for critical review and comparison testing of farm computer software, but the North Central Computer Institute (NCCI; University of Wisconsin, Madison) and Northeast Computer Institute (NECI; State College, Pennsylvania) are working in that direction. The *NCCI Software Journal* was recently launched as a vehicle for peer-reviewed articles describing software. NECI is developing a directory of agricultural software for which user friendliness, documentation, input and output formats, and internal documentation have been compared to minimum standards.

Agricultural Research and Development Agencies

Understanding the flow of agricultural research and development (R&D) is important in predicting the roles that various research and development agencies will play in computerizing agriculture. The private sector has a key role in product-oriented R&D. When basic research on a topic has progressed to reveal potential products, the private sector will ordinarily develop them to the stage at which they are marketable. At that point, public research agencies come back into the developmental process to integrate the product into useful systems, to compare the product with similar products, and to train farmers and others in the appropriate use of the product. For the most part, farm management research is in the public domain.

It is useful to think of a piece of agricultural software as being composed of a management component, namely the conceptual and technical information in the program, and a product, namely the computer code. Almost all the conceptual and technical information in farm-related software is and will be in the public domain, having been revealed in scientific journals, extension circulars and bulletins, and the farm media. In general, therefore, this information will not be protected by copyright. The associated computer codes, however, can be protected by copyright, since they are unique means of expressing and integrating the information. Thus there should continue to be adequate incentive for the private sector to invest in agricultural software development.

Political Aspects

In spite of an impressive record of innovation and accomplishment, the agricultural R&D system is still falling far short of meeting the need and capitalizing on the potential for computerizing agriculture. Great effort and investment will be required to create a nationwide agricultural network, linking all the important components of the production agriculture system, including public and private research and educational institutions and agencies, farms, and agribusiness. Large programs to develop the large integrated software systems, including simulators and expert systems, needed to manage the complex operations of modern farms seem justified. Such programs might involve teams of public and private scientists and consultants, private-sector software companies, extension people, agribusiness representatives, and farmers working together.

The public needs to understand how the agricultural R&D system operates in its behalf, because inputs of public money will be essential for R&D leading to agricultural computerization. Unlike virtually all other businesses in America, agriculture is made up almost entirely of relatively small businesses. Even the largest farms are not equipped or financed to mount a significant R&D effort. This has been left primarily to land-grant universities and USDA.

While American industry and agribusiness mount research programs of their own and support university research that is beneficial to production agriculture, they have ways, including patents and secrecy, of ensuring exclusivity and capturing most of the benefits of this investment. In production agriculture, however, newly adopted technology is disseminated as rapidly as possible. The agricultural information generated by institutional R&D programs is freely available, even to foreign competitors. Likewise, major U.S. agribusiness firms operating in foreign countries make new technology available to competitors of American farmers.

The net result is that most of the benefits of new agricultural technology accrue to early adopters of the technology and consumers. After a new technology, such as a new crop variety or useful computer program, is widely used by farmers, production and efficiency increase, leading to a corresponding increase in competition. Prices of the relevant commodity or commodities decline and thus the benefits of R&D, even site-specific applied research, accrue to consumers. This is a primary justification for broad public support of R&D in production agriculture.

The national "fuss" over formula versus competitive funding for agricultural research obscures the fact that the total production agriculture R&D effort is extremely underfunded. The annual return on investment in these activities ranges from 10 percent to more than 100 percent and averages between 30 and 60 percent, depending on the commodity (*11*). The long-term discounted marginal product of agricultural R&D is estimated at well over $5 for the last dollar invested in research on such major commodities as corn, wheat, and soybeans, suggesting that R&D input is low relative to returns. Low-income people of our nation gain most from agricultural R&D because food is a large item in their family budget, and their investment of tax money in agricultural research is relatively low.

According to my calculations, most major industrial firms invest 3 to 6 percent of their average annual cash receipts in R&D activities. The total investment in agricultural research directly supporting production agriculture is less than 0.7 percent of the cash sales of farm products. This level of R&D investment was adequate to sustain American agriculture when the only competition was a largely peasant agriculture in much of the world, but those days are gone. Like the steel and automobile industries, production agriculture is a highly competitive international industry. We must increase the flow of well-developed agricultural technology, including computer technology, to American farmers or we will lose our position of leadership in world agriculture.

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