Agricultural Research and Development

Public and Private Investments Under Alternative Markets and Institutions

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Introduction

Federal support for agricultural research and education has a long history. In the 20th century, public investment in agricultural research helped transform U.S. agriculture from a natural-resource-based industry to a science-based industry. As we move into the 21st century, the challenges facing U.S. agriculture are of a significantly different nature than when the public agricultural research system was first established. Society is asking the agricultural research system to address environmental, food safety, and rural quality-of-life issues, in addition to the traditional concerns about food costs and trade competitiveness.

Government supports research because of the "public good" nature of knowledge. This support can be in the form of direct funding or incentives for private research. The Federal Government has funded agricultural research at State universities for more than a century. These funds are increasingly in the form of project support instead of the traditional institutional (formula) grants. As tax dollars for research have become increasingly scarce, State research stations have increased their reliance on direct contributions from the private sector. Universities are also more aggressively patenting and licensing their discoveries.

Public science policy has moved to increase incentives for private agricultural research by strengthening intellectual property rights (IPR's) for biological inventions. These include protecting plant breeders' rights for new plant varieties and allowing utility patents for genetically engineered organisms. The use of IPR's for biological inventions has raised concerns that they could increase industry monopoly power to the point where new agricultural technology benefits only a narrow set of interests and eventually curtails progress in agricultural science. Regulatory policy also affects incentives for private research. Environmental and food safety regulations can significantly raise development costs for new technology and reduce incentives to conduct research. However, these regulations can also help achieve important social goals that market forces alone may undervalue.

Studies have shown that the past public investment in agricultural research has resulted in large economic benefits of at least 35 percent annual rate of return. From society's point of view, there has been underinvestment in agricultural research. A high (marginal) rate of return implies that additional dollars for agricultural research would result in substantial increases in economic growth, since it would earn a higher return compared with most other investments. As the capacity of the private sector to conduct applied agricultural research increases, the public sector can focus more resources on fundamental, or pre-technology, research. This research is necessary to release the underlying scientific constraints to technological advances. To ensure both continued efficiency and high returns from agricultural research requires close linkages between science-oriented research and technology-oriented research. This may require closer institutional linkages between public and private research.

Agricultural Science Policy in an Affluent Society

Scientific investigation, accompanied by the new knowledge it generates and the foundation it lays for the development of new technologies, is a cornerstone of economic development and human progress. Overall, economic returns to the U.S. public's investments in science and technology have been large. The origins of public support of science were in agriculture. For more than 130 years, the Federal Government has maintained a commitment to advancing agricultural science and education. This Federal commitment has helped transform agriculture from a resource-based industry to a science- and technology-based industry.

The role of public policy and public funding for R&D has recently received increased scrutiny and review, like most Federal spending given attempts to reduce the Federal deficit. Furthermore, the industry of agriculture and the role of agriculture in the economy have changed dramatically since 1862, when the U.S. Department of Agriculture (USDA) was established. At that time, the desirability of public investment in agricultural research was self-evident: agriculture was the occupation of most of the Nation's population. Today, society's interest in agricultural research is more complex and less obvious. The United States went from a largely rural population (where most people were employed directly in farming) to one where only 2 percent of the population are farmers. Moreover, changing consumer demands and new environmental and natural resource problems all affect the role and priorities for public agricultural research. Additionally, changes in the science base of agricultural research and the legal protection afforded to scientific discovery have enhanced the role of the private sector in agricultural research. These factors have important implications for the future of the Federal role in agricultural research.

Federal Science Policy and Agriculture: A Brief History

The concept that science is in the national interest underlies the Federal Government's role in the support of research. The first Federal commitment to science and technology was aimed at providing a scientific basis for the teaching of agriculture. In 1862, Congress passed the Morrill Land Grant College Act, which gave States and U.S. territories land that they could sell to develop colleges that would offer practical instruction in agriculture and the mechanical arts. Agriculture was then the business of the day: half the population lived on farms, and 60 percent of all jobs were connected to agriculture. Furthermore, farmers and farm families had little access to technical education. This legislation established a network of public institutions still known as the "land-grant colleges and universities." Because agricultural professors needed teaching material and a stronger scientific basis for their teachings, Congress passed the Hatch Experiment Station Act in 1887, which created a system of State agricultural experiment stations (SAES's) under the auspices of the land-grant universities. It also authorized the USDA, which was beginning to conduct significant amounts of inhouse agricultural research to channel Federal funding to the SAES's. Later, Congress took further steps to assure that knowledge and technologies developed at the SAES's and the USDA would reach those not enrolled in courses at the colleges. With the passage of the Smith-Lever Act in 1914, Congress created the Cooperative Agricultural Extension Service (a partnership among Federal, State, and county governments). Essentially, the Morrill, Hatch, and Smith-Lever acts were designed to deliver the practical benefits of education and scientific research to U.S. citizens, with the specific aim of improving the economic prospects and quality of life for farmers, farm families, and rural communities.

Agricultural science held a privileged position until World War II. As late as 1940, almost 40 percent of Federal expenditures for R&D ($29.1 million of $74.1 million) went to USDA inhouse and SAES-based research (Mowery and Rosenberg, 1989). No other sector of the economy benefited from the university-based research support granted by the Federal Government, through USDA, to the SAES's. Thus, the SAES's accounted for a large share of all research conducted at universities.

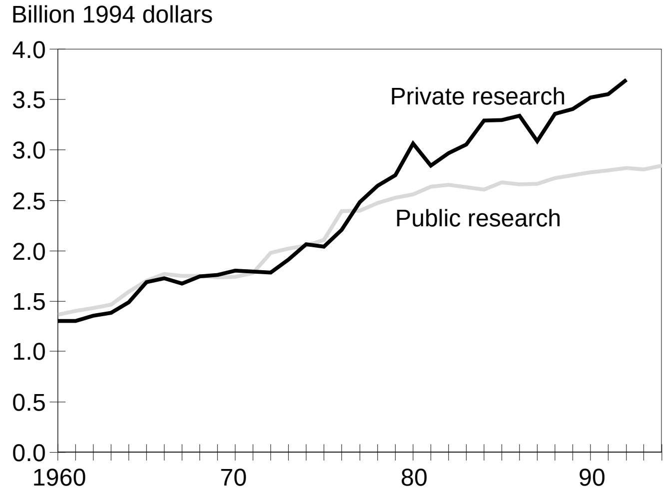
World War II transformed the U.S. R&D system. First, the Federal Government contracted extensive amounts of R&D with private firms. This arrangement significantly shifted federally financed research and technology development, particularly defense-related R&D, into industry. Since World War II, about 75 percent of all Federal R&D funds have gone to the private sector (Mowery and Rosenberg, 1989). Second, the war spawned huge increases in Federal R&D spending. National security concerns were often the principal drivers, including the Korean War, the Soviet launch of the sputnik, the Vietnam War, and the U.S. "energy crisis." Other social issues and priorities also motivated the expansion of Federal R&D investment, including the Great Society programs, environmental concerns, the "war on cancer," and recently, the international competitiveness concerns of U.S. industry and products. Until the late 1970's, the United States spent more on R&D than all other industrialized countries combined (Mowery and Rosenberg, 1989).

After World War II, other Federal agencies received increasing amounts of Federal science and research funding compared with USDA. Because defense-related research has dominated Federal R&D spending, the Departments of Defense, Energy, and NASA accounted for a very large share of Federal obligations for R&D (about 74 percent in 1991). Also, these agencies account for most Federal R&D funds going to industrial firms. However, university-based research also received a large boost from the opening of the National Science Foundation (NSF) in 1950 and the expansion of the National Institutes of Health (NIH). These agencies greatly expanded Federal support for university science and for the universities' research infrastructure. In 1991, NSF and Health and Human Services together accounted for almost 20 percent of all Federal R&D obligations and over two-thirds of Federal R&D obligations for universities and colleges.

By 1991, USDA expenditures for R&D were less than 2 percent of all Federal R&D spending ($1.2 billion of $61.3 billion). About 4 percent of Federal support for research at universities and colleges was for agriculture ($408 million of $10 billion). Agriculture's future share of Federal resources for science and research may depend on how society judges the benefits of agricultural research compared with other public investments. This requires clear measures of how agricultural science contributes to societal goals such as consumer health and safety, environmental quality, community economic development, and international competitiveness.

The government's role in supporting agricultural research also needs to adapt to the rising involvement by the private sector in conducting agricultural R&D. The post-World War II period has witnessed a significant increase in the private sector's contribution to the development of improved agricultural inputs and food products. Several factors have spurred private industry's interest in agricultural research, including scientific advances in biotechnology, increased market opportunities, and stronger intellectual property rights for biological inventions. Between 1960 and 1992, private spending for food and agricultural research tripled in real terms. Today, the private sector invests more in food and agricultural R&D than do the Federal and State governments combined (fig. 1). However, these raw totals for research expenditures mask a significant shift in emphasis in the type of agricultural research conducted in the private sector. In 1960, the areas of responsibility in research between the public and private sectors were clearly drawn. More than 80 percent of private research was for either improving farm machinery or developing new food products or processing methods. Public research concentrated on increasing yields of crops and livestock. Since then, the private sector has developed significant research capacity in areas that the public sector long dominated, such as plant breeding. By 1992, nearly 60 percent of private research was devoted to increasing crop and livestock yields by supplying farmers with improved crop varieties, agricultural chemicals, animal breeds, feeds, and pharmaceuticals (fig. 2). These trends suggest more potential for overlap between public and private agricultural research. The changing institutional structure of agricultural research in the United States has placed new stresses on the system while also creating new opportunities for technological advance.

Figure 1
Expenditures for agricultural research in the United States, 1960-94[1]



[1] Annual expenditures adjusted for inflation by cost-of-research deflator.

Sources: Economic Research Service. Private research data derived from Klotz, Fuglie, and Pray (1995); public research data derived from U.S. Department of Agriculture, *Inventory of Agricultural Research*.

American Society and Agricultural Science and Technology

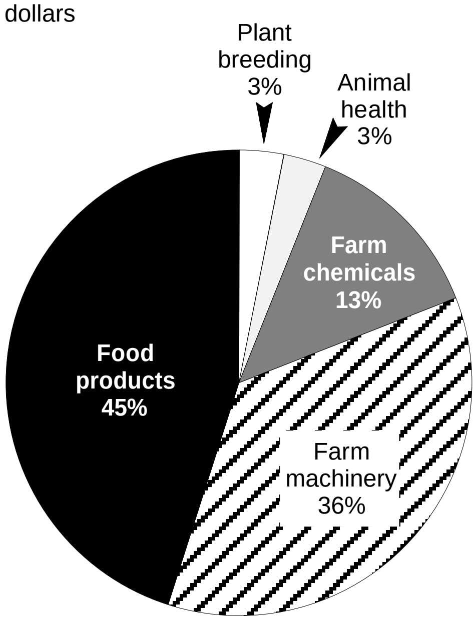
The changing roles of government and private industry in agricultural research partly reflect the changing structure of the American economy. The demands placed on the agricultural research system by farmers and consumers have changed considerably over the past century.

Agricultural Technology and the Needs of a Developing Economy

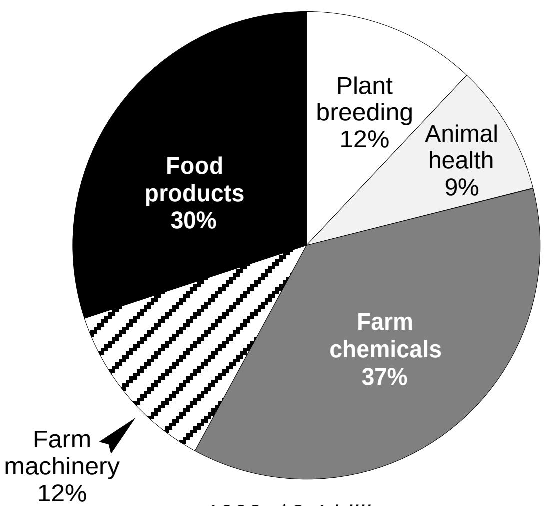
The Federal Government's first commitment to agricultural science came at a time when farming was the

Figure 2
Private agricultural research, by industry

Nominal dollars



1960: $206 million



1992: $3.4 billion

Source: Economic Research Service. Data derived from Klotz, Fuglie, and Pray (1995).

major economic activity in the United States. When the Morrill Act was passed, farmers had little access to formal education to improve their economic status. By the time the 1887 Hatch Act was enacted, the need for a science base to underpin the teaching of agriculture and the development of agricultural technology had been recognized (Cochrane, 1979).

The science of agriculture in these early years was influenced by both supply-side factors (developments in fundamental science to which agricultural scientists had access) and demand-side factors (demand from farmers for improved farming methods and new production inputs that could reduce costs and improve profitability). On the supply side, for example, Justus von Liebig's 1840 book, *Organic Chemistry and Its Application to Agriculture and Physiology*, had a major effect on soil fertilization recommendations (Cochrane, 1979). Also, the rediscovery in 1901 of the Austrian monk Gregor Mendel's work on heredity established the modern science of plant genetics. Early experiment stations also had to recognize the demand side, or technical needs, of their farm constituencies. For example, early biological innovations were often practical, like identifying the most suitable varieties and agronomic practices for growing small grains crops in the Plains States. Nineteenth-century biological innovations also included increasing dairy productivity in the East and Midwest and developing a successful horticultural industry in California (Olmstead and Rhode, 1993). Cochrane writes that, "Perhaps a dozen agricultural experiment stations were doing highly professional work in the agricultural sciences by 1900. Once the scientific properties and relations of plants, animals, and the soil were understood, the technologies for combating plant and animal disease and for increasing yields could begin to flow forth. And they did so after 1900" (Cochrane, 1979, p. 245).

For many decades, economic forces probably were the strongest influences shaping agricultural science and technology in both the public sector (at the experiment stations and USDA) and the private sector. Thus, while science and technology change the face of society, they are simultaneously responding to society's needs. A conceptual framework for examining how economic forces affect the rate and direction of technical change is the induced-innovation model. This model assumes that innovators (who may be farmers, entrepreneurs, or scientists) develop new technologies that conserve increasingly expensive resources and use relatively less expensive ones. In the induced-innovation model, a rise in the price of petroleum-derived energy, for example, would induce the development of more energy-efficient machinery and alternative energy sources.

The induced-innovation model explains why farm mechanization was the first wave of technological change in U.S. agriculture. Mechanization got underway in the 1830's, but surged during 1860-1900. It was spurred first by the manpower shortage on farms during the Civil War, and again when farmland more than doubled as the Nation expanded westward in the late

1800's (Cochrane, 1979). The introduction and expansion of mechanical technology was not meant to increase yields but instead to ease the substitution of power and machinery for relatively expensive labor. Mechanical innovations continued to reduce labor inputs in farming for decades. Labor inputs declined 35 percent between 1948 and 1960, and another 47 percent between 1960 and 1990 (USDA, 1994). Sophisticated soil preparation and planting and harvesting machinery, in combination with the internal combustion engine, removed most of the hard physical labor from farming, reducing the amount of labor in farming to a small fraction of total costs.

The induced-innovation model also helps explain why, following the close of the land frontier in the early 20th century, yield-increasing technologies began to be developed and introduced on a significant scale. Plant breeding was aimed at producing more fertilizer-responsive varieties that were also resistant to drought and diseases. This breeding significantly increased yields per acre of corn in particular, but also for soybean, cotton, wheat, and most other crops. In the post-World War II period, the development and application of biological and chemical technologies intensified. Use of commercial fertilizers increased dramatically during this period, contributing importantly to increases in crop yields. Hayami and Ruttan (1985) argue that declining real energy prices (in relation to land and labor costs) induced the development and widespread adoption of petroleum-based agricultural fertilizers and chemicals.

Animal production technology also improved significantly after World War II. Feed conversion rates in poultry improved dramatically; modern drugs and vaccines effectively curtailed animal disease; and knowledge of animal nutrition improved animal feeding practices (Cochrane, 1979).

Scientific discovery and agricultural technology development have contributed to remarkable increases in farming productivity. From 1948 to 1991, total factor productivity (farm output per unit of total factor input) increased nearly 150 percent (USDA, 1994). Productivity growth in farming, in turn, contributed to the growth of the national economy. This is because more food and fiber could be produced using fewer of the Nation's resources; thus, other sectors could grow more rapidly at less cost. In addition, since farm commodities could be produced more cheaply, food and fiber products could be priced reasonably. Consequently, consumers had more income to spend on other goods and services. In fact, an important indicator of a country's level of economic progress is the portion of its citizens' disposable personal income spent on food. In the United States that portion was slightly above 11 percent in 1992, in contrast to 22 percent as recently as 1949 (Dunham, 1993).

Agricultural science has contributed to both abundant, reasonably priced food for U.S. consumers and making U.S.-grown farm and agricultural products available to people in the rest of the world. Significant percentages of some U.S. commodities are exported. For example, about 60 percent of wheat production and 30 percent of soybean production are exported. Agricultural products compose about 10 percent of all U.S. merchandise exports (Economic Report of the President, 1995). Today, science continues to support the global competitiveness of U.S. agriculture, but it is also increasingly turning its attention to addressing other societal issues related to modern farming.

Demands of an Affluent Society

The U.S. economy has changed dramatically since the early years of public investment in agricultural education and research. Farming now directly accounts for only a small share of national economic output and national employment. This is largely because of the significant achievements of agricultural science. However, if we define agriculture more broadly to include activities beyond the farmgate (such as food and fiber processing, marketing, and retailing), it still accounts for about 18 percent of U.S. jobs and more than 15 percent of the Nation's gross domestic product (*Economic Report of the President*, 1995). Decisionmaking in this huge agribusiness sector is increasingly driven by modern consumer concerns regarding nutrition and health, food safety and quality, convenience, the environment, and even ethical considerations such as animal welfare. The role of agricultural science and technology, and of public policy more generally, in addressing this array of modern-day issues is still evolving.

Many modern consumer demands are well articulated in the marketplace. The market appears to respond readily to demands for more varied, convenient products with desirable sensory attributes like taste and appearance. An excellent example of a market response is the recent development of the U.S. kiwi fruit industry. This industry did not exist until U.S. consumers developed a taste for the fruit after being introduced to kiwis from New Zealand. Another example is the shift of U.S. meat consumption to more poultry and less beef. This shift was based partly on nutrition and health information. It demonstrates how health concerns can drive the composition of products in the marketplace. An increase in market demand for food products with sensory or other easily discernible characteristics can induce firms to develop new products with these attributes.

The market may respond inadequately to other types of consumer preferences. It may, for example, undervalue consumers' demand for environmental goods, nonsensory attributes of food products (like safety and nutrition), and attributes that meet ethical or religious standards. A consumer may be unable to identify these attributes simply by looking at, feeling, smelling, or tasting products. If consumers cannot "vote" for these product characteristics by changing their consumption patterns, then market forces may be unable to drive new product and technology development in a direction that meets these demands. Public policy may be useful in providing the basis for better-informed consumer choices that can then signal food manufacturers and product developers. Examples of such policies are: requiring that certain scientific information be provided through labeling, setting food safety standards, and providing product certification standards (like those for organic produce). Because of relatively weak private incentives, there may be a stronger justification for public investment in agricultural science and alternative technologies directed toward enhancing these "public goods."

Again, the induced-innovation model can be used to explain why technology development may have provided less of these public goods than was optimal from society's point of view. For example, the model can be applied to the development of chemical-intensive farm production technologies. The expansion of the use of agricultural chemicals increased agricultural productivity significantly, as discussed above, but also negatively affected farmworker health, water quality, and wildlife habitat. These negative effects impose costs on society that are not reflected in costs of production borne by farm owners or the market prices of farm products. In other words, the social costs of farm chemical inputs exceed their private costs. Moreover, consumers have become increasingly concerned about these social costs in recent years. Unless the private costs are brought more in line with social values, the induced-innovation model suggests that agricultural research will overemphasize technologies that use chemical inputs and underinvest in technologies that conserve them (Ruttan, 1971).

Besides their environmental concerns related to onfarm chemical use, today's consumers express concern over health risks associated with exposure to chemicals through food consumption. Individual consumers have many different degrees of willingness to accept health risks; in other words, the same detailed knowledge of the health risk may result in different buying habits by different consumers. However, national polls show that most consumers express some form of concern about exposure to chemicals used in producing, storing, and processing foods.

Some modern agricultural technologies, such as biotechnology (especially recombinant DNA), have also generated consumer concerns about their potential health and environmental effects. Biotechnology is being used to develop plants that are more resistant to pests, disease, and herbicides; plants that fix atmospheric nitrogen; plants with the ability to tolerate drought and frost; animals with increased lean muscle tissue and milk production; and microorganisms with improved properties for fermentation in food processing. Agricultural biotechnology is also being used to improve such food quality traits as flavor, texture, shelf life, or nutritional content, and to develop foods with decreased toxins and allergens. These new technologies have tremendous potential benefits. However, concern has been raised about whether agricultural biotechnology products pose added risks to environmental quality and to human health (Reilly, 1989; Caswell, Fuglie, and Klotz, 1994). Increased research and education may be needed to understand these effects more thoroughly.

Sometimes consumer concerns regarding farm production technologies take on social and ethical dimensions. Worker rights and safety and animal welfare are social issues that can result in preferences of some consumers for food products produced in certain ways. For example, some consumers prefer "dolphin-safe" tuna (tuna harvested without the possibility of dolphins being ensnared in the nets) or "free-range" chicken (from poultry raised in less confined conditions). Again, these types of food attributes may be difficult for consumers to detect unless reliable information is available. Therefore the market may undersupply such attributes.

Despite the relative abundance and accessibility of food in the United States and other developed nations, nutrition and diet still strongly affect human health. These linkages are increasingly recognized and studied. Heart disease, cancer, stroke, and diabetes—the four leading causes of death in the United States—have been linked to diet. Proper diet might forestall at least 20 percent of the annual deaths from these four causes (National Research Council, 1989a). Hypertension, osteoporosis, and obesity, which affect productivity and lifespan, are also diet-related. These seven health conditions cost society an estimated $250 billion each year in medical costs and lost productivity (Frazão, 1995).

The food industry is bringing numerous new products to the market. Often, these new products are responses to growing consumer awareness of dietary risks, particularly now that labels allow consumers to assess a product's nutritional content. The private sector may still have relatively little incentive, however, to conduct the research that reveals the underlying links between diet and health.

Environment, food safety, and health risk concerns have provided a particularly difficult set of issues for science research and technology development. The economic benefits of research arise from satisfying consumer demands at the least cost. In the areas of environmental degradation, food safety, and health risk, however, much evidence suggests that consumers' perceptions of risks often vary markedly from scientific assessments (Kramer, 1990; Breyer, 1993). Thus, public research may poorly serve the public interests (at least as evaluated from a scientific perspective) when the research focuses only on consumer demands. The fact that the science is incomplete and uncertain makes the problem more complex. Given the mass of often conflicting information about risk, consumers may have difficulty distinguishing accurate information from false claims. Under such circumstances, they may exhibit skepticism of all claims from the scientific and health communities.

Economics of Science Policy

The changes in consumers' expectations of and farmers' needs from agricultural technology help explain why the U.S. agricultural research system has moved in new directions since the mid-19th century. It also puts into perspective some questions about Federal policy toward agricultural R&D concerning funding levels, research resource management and allocation, the role of intellectual property rights, and the division of labor between public and private research. Economic theory can provide a framework for addressing science and technology policy questions.

A basic economic argument underlying public policy toward science and technology is that the private sector tends to underinvest in research. This is because the inventor can only appropriate the product of research, new knowledge, to a limited extent. Once new knowledge is sold, it is no longer possible for the inventor to continue to sell it because any one purchaser can reproduce the information at little cost (unless the inventor can somehow exclude nonpayers from using the invention).[1] The benefits from research that the inventor cannot capture are called "spillovers." They include benefits to rival firms that can copy the invention or use it to develop new inventions. Spillovers also include benefits to consumers from lower priced or improved products. Since the profitability of research for inventors (private benefits) is smaller than benefits to society (which include the spillovers), profit-oriented individuals and firms will often underinvest in research (Nelson, 1959; Arrow, 1962).

The presence of large spillovers provides an economic rationale for direct public support of research, either through a publicly operated research system or through contracting with private firms. The spillover principle explains why only the largest private corporations invest in significant amounts of basic research, and establishes a clear public role for the support of fundamental science. Large spillovers can also result from applied R&D. Empirical studies show that innovating firms capture only about half the social returns from industrial R&D (Mansfield and others, 1977). Similar results have been found for agricultural R&D conducted by the private sector (Huffman and Evenson, 1993).

Although direct public support of research successfully addresses the spillover problem, public support itself may contribute to other forms of inefficiency. A real world disadvantage of government funding of programs is the lack of incentive for cost control in situations where performance monitoring is difficult. In the private sector, market competition disciplines firms to control costs. Inefficiency resulting from lack of cost control in conducting research may not, however, be a serious problem for the public agricultural research system in the United States. The decentralized nature of the system, in which most research resource allocation decisions are left to the directors of individual State agricultural experiment stations (SAES's), tends to reduce this source of inefficiency. This is because it fosters competition among the States. Ruttan (1980) likens this system to 50 competing firms in a market economy. Nonmonetary rewards, such as professional prestige, also motivate scientists not to waste time and resources.

Perhaps a more serious potential deficiency of public funding of research is the way information is acquired and processed in allocating research resources. Answers to two fundamental questions determine the value of any proposed research project: (1) what is the likelihood that the research project will be successful in making a scientific or technological advance? and (2) supposing the project is successful, what is the value of the scientific or technological advance to society? (Ruttan, 1982). Selecting the best portfolio of research projects requires information on both questions. Judgments about the first question are best provided by the leading scientists in the field. Analysis of the second question requires up-to-date information on market demand, re-

[1]Knowledge has the two classic characteristics of a public good: non-rivalry (use of knowledge does not reduce the amount available to others) and non-excludability (others cannot be prevented from using knowledge once it is first made available) (Samuelson, 1954). Another reason private firms underinvest in research is that it is often a high-risk undertaking (Arrow, 1962).

source scarcities, and consumer preferences. Wright (1983) argues that when the answers to these questions are complex, research efficiency is enhanced by an R&D system that relies more on private sector entrepreneurs rather than on a public administrator. Encouraging private entrepreneurs to undertake research allows exclusive private information to be incorporated into research decisionmaking and revealed in the marketplace.

Providing intellectual property rights (IPR's) for new inventions is an important policy tool for encouraging the private sector to conduct research. IPR's (such as patents, plant breeders' rights, and trade secrets) allow the inventor to exclude others from making, using, or selling the invention for a limited period. Patents also encourage inventors to publicly disclose their discoveries. Patents are awarded for inventions considered new, useful, and not obvious to an expert in the field. To receive a patent, an inventor must describe the invention in sufficient detail so that someone skilled in the art can reproduce it. The degree of the monopoly afforded by a patent depends on its duration (17-20 years in the United States) and by the breadth of exclusion (as defined by the patent claims) given to the owner. Plant breeders' rights, which extend for 20 years, are awarded for new varieties of crops that are distinct, uniform, and stable. Plant breeders' rights protect only the reproductive material of the plant. State statutes protect trade secrets if they are kept confidential. Trade secrets may be kept out of the public domain indefinitely.

IPR's reduce the spillover problem by enabling the inventor to capture a greater share of the benefits from new technology. In many cases, an inventor (or his licensee) will be unwilling to make the investment necessary to commercialize the invention unless he can be assured of a market for the product. A patent grants such a monopoly, at least for a limited period of time. However, a monopoly also generates welfare losses. This is because a monopolist will generally charge a higher price for a product (and produce less) compared with a competitive market. Therefore, once an invention is commercialized, patents may lower the social value of an invention, although it is preferable to having no invention at all. The tension between these two types of market failure underlies much of the public policy debate about intellectual property rights. How these rights are defined and enforced carries implications for both economic efficiency and equity. Inventors often favor stronger intellectual property rights so that they may obtain the largest possible share of the social benefits of their invention. Consumers and other users of an invention, on the other hand, seek to limit the monopoly power of an IPR in order to increase the availability of the invention and reduce its cost.

Market failure also affects the direction that new technology takes. Since markets are frequently incomplete (that is, market signals, such as prices, may fail fully to convey social values or consumer preferences), private incentives to develop certain technologies are reduced. Prices provide an important indication of resource scarcity and product demand. According to the induced-innovation model, firms respond to these signals by investing in specific, new technologies. To the extent that market signals do not reflect societal interests (such as the demand for environmental amenities or food safety), the private sector will tend to underinvest in technologies that meet these demands. For example, if the social cost of using certain inputs exceeds their private cost, then market incentives will favor the development of technologies that use those resources at the expense of technologies that conserve them (Ruttan, 1971). Another example is food safety and nutrition. Detecting nonsensory attributes of food products is often difficult (sometimes impossible) for consumers. Without a system of safeguards, standards, or information labels, private companies have little incentive to develop products with enhanced nonsensory characteristics (such as higher vitamins, lower fat, or fewer chemical residues). Establishing rules and regulations in the agricultural and food industry is one policy approach to overcome these kinds of market failures. However, the costs of complying with regulations may be greater than the benefits. Regulations can also have unintended effects on market structure.

Although this economic framework provides some general guidelines for public science policy, it gives few prescriptions about the best way to support R&D. Each alternative policy approach, whether to increase direct public funding of research, strengthen IPR's, or correct market imperfections, involves trade-offs among competing objectives. The economic argument for direct public support of research is perhaps clearest for basic research since it has large positive spillovers. This may also include many kinds of applied research and technology development where market incentives do not provide for sufficient private interest. On the other hand, budgetary and managerial constraints limit government support of research. Private companies are more responsive to changing user needs, and market competition disciplines their efficiency. Intellectual property rights, regulations, and other types of market interventions can partially correct for the lack of appropriate market incentives. However, this is often at the cost of generating other kinds of inefficiencies. Determining the appropriate design of science policy requires analysis of the relative size and significance of these trade-offs.