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Is Agricultural Research A Good Investment?

Dana L. Hoag
Eihlab Fathel-Rahman

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Colorado State University

PURPOSE AND USE OF THIS PUBLICATION

In recent years a considerable literature has been published about returns to research in agriculture. This report does not attempt to add to the literature with new data or analyses. Our purpose is to summarize what has been learned for a broad reader audience.

This report is organized by concepts, such as what agricultural research is, the costs and benefits of research, comparisons between public and private research, the returns to agricultural research investments, and gains in productivity due to research. We drew from available literature as much as possible to make each section complete. Sometimes, that meant that we could not compare information all from the same year or that we had to compare everything in the year of the oldest study, since different types of studies came out in different years.

Anyone interested in a more detailed analysis of this area is encouraged to look at the references cited in this report.

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SUMMARY

Agricultural Research is a Valuable Investment

In 1999, researchers at Colorado State University spent $36 million on agricultural research topics ranging from ***A***phids to ***Z***oo nutrition. Most people don't think very much about the benefits from these investments, since most Americans take feeding themselves for granted. Nevertheless, these benefits are impressive. American farmers can produce 2.5 times more output per dollar of input than they could fifty years ago (Ahearn, et al., 1998). Therefore, only about 1 percent of our population is required to produce all the food we need. About half of the remarkable productivity gains in agriculture came from public investments in research and development (R&D). One-quarter was from public investments in infrastructure, and one-quarter came from changing input levels or private investments in research (Shane, et al., 1998).

Research makes society better off in many ways. For example, research provides:
1) More discretionary income -- The huge productivity gains of the last fifty years have freed up labor and resources for new challenges. Americans are free to spend 90 percent of their income on goods and services that are not necessary for basic survival; goods such as computers, preprocessed foods, and services such as entertainment, personal trainers, and cable television. Spending less on food improves the lives of everyone because the savings can be used to make society a safer, cleaner, more desirable place to work and live. More resources can be allocated toward creating a cleaner, more attractive environment, for example. We use about half as many acres to grow crops in the United States with today's technology than we would use if we farmed with technologies available in 1950. That means less habitat destruction, less soil erosion, and cleaner water (Avery, 1998).

2) A better economy—The United States is a leader in agricultural production. In Colorado, for example, farmers and ranchers directly or indirectly support 105,140 jobs in related businesses, which generate nearly $16 billion in annual sales. In addition, U.S. agricultural exports account for one-fourth of all agricultural sales, which helps reduce our trade deficit.

3) Answers to questions-- Research helps society by providing answers to important questions. Referendum 14 in the 1998 Colorado general election, for example, asked voters whether they wanted more regulation on confined animal feeding operations (CAFO's). The issue was divisive enough to be a 1998 ballot initiative because many towns had been struggling to balance property rights, environmental concerns, labor issues, and the economic benefits that CAFO's might bring to a community. As shown inside this report, research helped answer questions related to CAFO's such as: how many people are employed by a typical CAFO, how much tax revenue is generated, whether real estate prices will go up or down, and how serious pollution issues are.

Clearly, research delivers benefits, but is it worth the cost? The answer is yes! Over two-dozen studies found that the financial returns to investments in agricultural research ranged from 30 to 90 percent (Fuglie, et al., 1996). This is a good return by any standard. Basic research returns the most per dollar invested, followed by pre-technology and technology innovation (applied research), and then by extension. The difficulty of estimating returns is evident by the wide range of these estimates, but studies agree time and again that the returns are high.

The Future of Agricultural Research

Despite the remarkable contributions of agricultural research to society, public funding has been flat, or declining, in real terms (inflation adjusted) since the 1970's. Agriculture receives less than 2 percent of the federal research budget, even though productivity in the agricultural sector grew 4-10 times faster than other sectors. Research was the primary reason that agricultural outpaced other sectors (Shane, et al., 1998). Nevertheless, private firms have had to pick up the slack in research spending. They currently spend one-third more than the federal and state governments combined, and their funding levels have increased by 3.5 percent per year after adjusting for inflation (Fuglie, et al., 1996).

Agricultural research has been proven to be one of the best investments this country has ever made. Unfortunately, however, public funding has been flat while our needs have increased and agricultural and resource issues have become more complicated. Some of the gains we see today are a result of investments made fifteen or more years ago. Therefore, people in the future will suffer the consequences of under investing today, and it will take them up to thirty years to recover (McCunn and Huffman, 2000).

In a recent survey about agriculture by Christenson, et al. (1995), a random survey of American adults said that they would allocate 45 percent of taxpayer money beyond high school for educational services to teaching; they would provide 25 percent for research and 30 percent for off-campus educational technical help. Therefore, the American public thinks research and extension are important. Why then are public investments in agriculture stagnant? Politically speaking, there are many reasons that research investments are difficult to justify. First, there is the time lag from investment to return. Most politicians cannot show that they made prudent use of taxpayer dollars for research when the returns to their investments occur ten, twenty, or even thirty years later. Second, there is spillover. Political figures need to show how their own constituents benefited, not how somebody else benefited in another state. Third, benefits are difficult to observe. Everybody in America, for example, benefits from being educated, but it is difficult to see the benefit of education directly in our daily routines. For the public to buy into the idea that more research is needed, they must be shown how their lives have been improved. This is a difficult task, however, because most of the benefits from research are taken for granted.

One option is to keep public funding static, or to reduce it, thereby allowing the private sector to increase its relative share of research. This option is undesirable to most people, however, because information developed by industry is kept proprietary. In addition, some research areas would be neglected because their benefits would be hard to capture. The public sector needs to fill voids that the private sector neglects. For example, basic research has the highest return of any type of research, but the private sector devotes only 15 percent of their research budget to basic research compared to almost half of the budget in the public sector. The public sector allocates more for basic research than the private sector because the benefits are hard to capture by the supplier of the research. Despite the proven track record of high returns to basic research, and the demonstrated need for the public sector to conduct basic research that the private sector will not do, there is a noticeable trend for public researchers to focus more on applied research.

INTRODUCTION

Coloradoans have much to be proud of when it comes to agriculture (Figure 1). Our state ranks seventeenth nationally in cash receipts and is a top five producer of potatoes, sunflowers, winter wheat, carrots, lettuce, onions, cattle on feed, fed cattle, and sheep. Agricultural businesses in the state directly support over 100,000 jobs and generate sales of almost $16 billion annually. Every job in agriculture indirectly generates nearly two more jobs elsewhere in the economy, and every dollar of agricultural product sold yields another dollar of sales to other businesses (Hine, et al., 2000).

Figure 1: Colorado Agriculture's Economic Contribution 1997

- 28,268 farmers/ranchers
- About 38,500 jobs on farms/ranches, and 105,140 in agriculturally related businesses
- Agribusinesses: $15,868 billion gross sales
  - $2.5 billion net income
  - $3.3 billion value added
- $22.8 billion farm assets--$19.2 billion equity.
- 985 million in exports (one fifth of state exports)
- Ranked seventeenth nationally in cash receipts

Source: Adapted from Hine, et al., 2000

Rapid agricultural productivity growth in Colorado reflects a national trend. In the last 50 years farmers and ranchers in the United States have increased productivity by almost 2 percent every year (Ahearn, et al., 1998). Remarkably, these advances were achieved with no increase in the real cost of inputs used. As a consequence, the United States now produces two and a half times more output while spending slightly less on land, labor, and physical inputs than it did fifty years ago. This increase in productivity has reduced food expenditures for American consumers to only 11% of their income, allowing them more discretionary income for non-agricultural purchases than most people in other countries.

Most of this prosperity is due to research and development. One USDA study (Shane, et al.,1998) concluded that 50 percent of the growth in agricultural productivity came from public investments in research, and 25 percent from public investments in infrastructure (e.g. roads); the remainder came from added labor, capital, and materials. This impressive return to agricultural research demonstrates how important public investment in research can be. Research is not free however. Many resources, both public and private, are used in the pursuit of knowledge, and these costs must be compared to benefits to determine whether there has been a positive net benefit.

Several studies have looked at the returns to investments in agriculture and concluded that the costs have been well worth it (see Tables 4 and 5). Investment returns range from 30 to 90 percent for research and from 23 to 45 percent for extension outreach to transfer knowledge from researchers to the general public (Table 3).

The purpose of this report is to discuss how and why public funds are invested in agricultural research. Universities and other public institutions are under increasing pressure to justify the value of their research funding. Therefore, in the following pages, we discuss what agricultural research is, why the government spends tax dollars to fund research, the costs of research, how net benefits are measured, and what studies have concluded about the net benefits and costs of research.

WHAT IS AGRICULTURAL RESEARCH?

Research is an investment in knowledge. Agricultural knowledge can increase yields and incomes, it can make production easier and less costly, and it can improve our well being through better quality goods and a cleaner, safer environment. Society invests in knowledge to improve net social welfare, measured in both monetary and non-monetary terms. Investments today also help future generations.

Types of Agricultural Research

Research can be divided into two categories, "basic" and "applied." Basic research is conducted to gain a more complete understanding about a subject, without an application or end use in mind. Applied research seeks to gain knowledge about a specific, recognized need for an existing problem. Huffman and Evenson (1993) divide research into four categories, two basic and two applied, as shown below in Table 1. General sciences such as mathematics, physics and chemistry lie outside of agricultural studies. Pre-technology sciences, such as animal genetics or agricultural economics, are the value-added sciences within agriculture that reprocess basic sciences into a more relevant format for the applied sciences. For example, in the pre-technology stage animal geneticists apply basic science concepts from genetics to animals. In the technology innovation (applied) research stage, animal scientists may use this knowledge to improve specific breeds. In the final stage, product development/technology transfer, private companies package ideas into saleable commodities, and public educators, such as the cooperative extension service at land-grant colleges, educate people about how to use new technologies.

Table 1: Research Classification With Examples

Types of Research/Science	Examples
• *General (basic) Sciences* – Fundamental knowledge	Mathematics, Physics, Chemistry, Biology Economics, Zoology, Genetics
• *Pre-technology Sciences* –Enable technology innovations without specific end use in mind	Engineering, Soil Chemistry, Nutrition, Computer Science, Agricultural Economics, Animal Genetics
• *Technology Innovation (Applied) Sciences* – End use of new technology	
▪ Natural Resource Sciences	Soil Science, Hydrology, Climatology
▪ Plant Sciences	Agronomy, Horticulture, Forestry
▪ Animal Sciences	Animal Breeding, Veterinary Medicine
▪ Post harvest Sciences	Food technology, Human Nutrition
▪ Social and Crosscutting Sciences	Agricultural and Resource Economics, Biological/Agricultural Engineering
• *Product Development/Technology Transfer*- Package and promote ideas	Private companies, Cooperative Extension

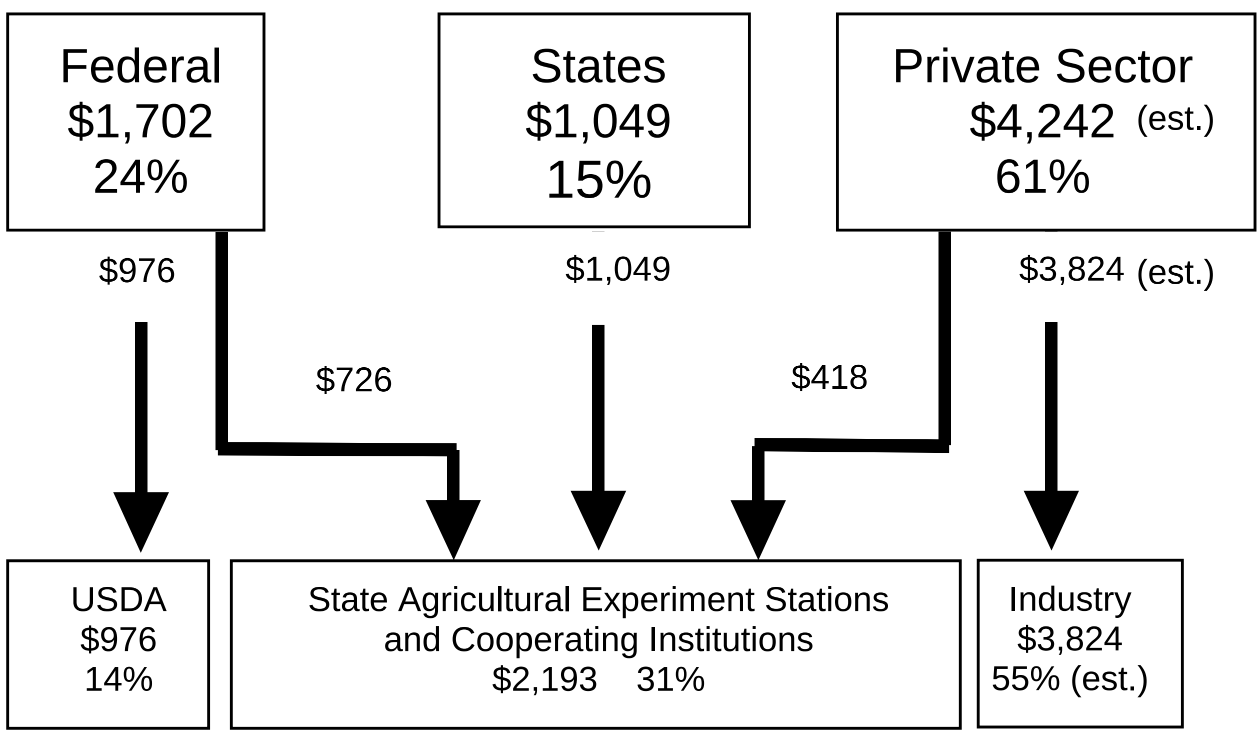
Source: Adapted from Huffman and Evenson, (1993)

WHO PAYS FOR RESEARCH?

Total public and private funding for agricultural research was an estimated $7 billion in 1995. As shown in Figure 3, on average in the United States, the federal government provides 24 percent of funding for agricultural research, states and local governments cover 15 percent, and the private sector picks up the remaining 61 percent. About 57 percent of the $1.7 billion spent by the federal government supports research at the United States Department of Agriculture (USDA). The remainder, administered by the Cooperative State Research, Education and Extension Service, funds research at the State Agricultural Experiment Stations (SAES), located at each land-grant college as well as providing competitive grants to public and private institutions. The private sector outspends the federal and state governments combined and it funded about 20 percent of the SAES program ($418 million in 1995).

Figure 2: Sources and Flows of Funding For Agricultural Research

in 1995 (Millions) $)



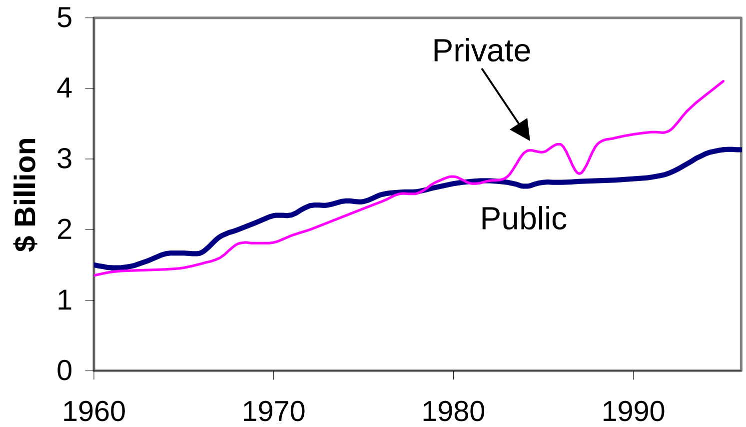
Source: Fuglie and Schimmelpfennig (2000)

WHY PUBLIC AND PRIVATE FIRMS INVEST IN RESEARCH

Public Research

Research and development (R&D) is a shared responsibility of individuals, industry, and the public. Forty years ago the private and public sectors shared research costs evenly (Figure 3). In 1996, the private sector spent one third more than the public sector.

Figure 3: Public Versus Private Spending for Agricultural Research



Source: ERS, 1997; Fuglie and Schimmelpfennig, 2000.

Private firms conduct research when they can make a profitable return on their investment. But why do governments provide funding for research? Generally, the government funds research that would not be undertaken by the private sector. Financial returns from some investments can be hard to capture because they are widely distributed, like the returns to education, or because they are not financial in nature, such as environmental protection, food safety and equitable resource distribution. The private sector is reluctant to invest in research in these situations because they are not the sole recipients of the fruits of their investments, which may mean they cannot recover their investment costs. Basic research, for example, produces higher rates of return than applied research, but the benefits are hard to capture. Therefore, the government funds more basic research than does industry. In principle, the government fills voids in private research.

There are at least five major reasons that the private sector lacks incentives to do research that the public would choose (Figure 4). However, just like private firms, state and local governments lack incentives to do certain research too, particularly research that will *spill over* into other localities. State governments have an incentive to under invest and to free ride off of states that invest heavily in agricultural research. Society is the loser if profitable investments go unrealized because states do not want to subsidize other states. Therefore, the federal government funds research at the state level and community level to avoid inefficiencies caused by political boundaries.

The government has a very good research track record, with returns that are as much as two times greater than average private investment rates. It conducts *direct* agricultural research through a vast network of agencies and universities. And, *indirectly*, the government facilitates private investment in a variety of ways, including grants, tax breaks, patent protection, cost-sharing, and public-private collaboration.

Private Research

While it has different incentives, the private sector has great interest in agricultural research too. Over the past 30 years, private spending for food and agricultural research tripled in real terms and today the private sector spends about one-third more than all states and the federal government combined. The role of private research has changed over time. In 1960, 80 percent of private research was for farm machinery or new food products or processing methods. By 1992, 60 percent was devoted to increasing yields through technologies traditionally supplied by public research, such as improved crop varieties, animal breeds, and pharmaceuticals.

The Future

Private sector research will likely grow faster than public research as government budgets for research shrink and as firms learn better ways to earn high returns through proprietary research. Dwindling public research dollars will result in lost benefits to society where the private sector does not pick up the slack. Until now the benefits of public research have proven to be very important. Public research has an average return that is one-third higher overall than the private sector, and two times higher for basic research. Returns are greater in the public sector because it can provide research when the benefits are non-proprietary (basic research) or non-pecuniary (social research for equity and a better quality of life).

Figure 4: Why The Government Does Agricultural Research

Financial
Even when benefits outweigh costs, the private sector cannot always recover its investment costs. Examples of these "public goods" include resource conservation, food safety, equity and education. In these cases it is difficult to guarantee that the benefits will accrue to companies that pay for research. The distribution of benefits does not create an incentive problem for public research since the general public pays for and receives the benefits of research.

Risk
Many good ideas are too risky for a single firm to address by itself. The government can spread risks out over many people and therefore lower the costs to the point that no single individual risks a catastrophic loss.

Scale
In some cases, a task is simply too large for a single firm to undertake. The government's size and resources may enable it to take on these projects.

Organization
Organizational structure can give the government an advantage. For example, federal-state partnerships in Agricultural Experiment Stations provide an opportunity to divide and share research and information that may not be shared in the private sector. The Agricultural Experiment Stations in Kansas and Colorado, for example, cooperated to develop wheat that is resistant to the Russian Wheat Aphid.

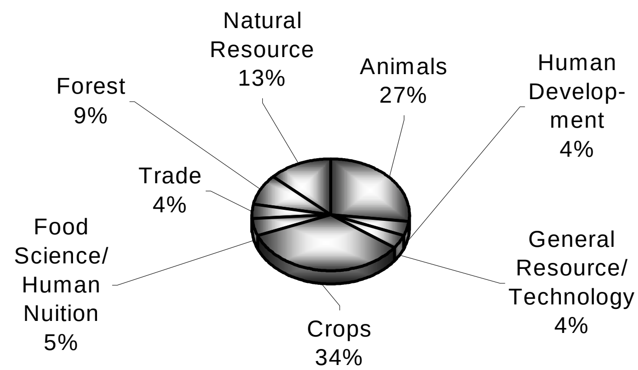
Legal
The government sometimes has fewer legal constraints than private firms. For example, the government cannot be sued in many cases where private firms can be.

FUNDING PRIORITIES IN THE PUBLIC SECTOR

Funding by Program

The allocation of public expenditures across program areas has been relatively constant (Figure 5), with about 70 percent spent on crop, livestock, and forestry research and about 13 percent on natural resource conservation and management (soil, water, and wildlife). Areas with less funding include trade, food science/nutrition, and human development.

Figure 5: Allocation of Agricultural Research Expenditure by Program 1996

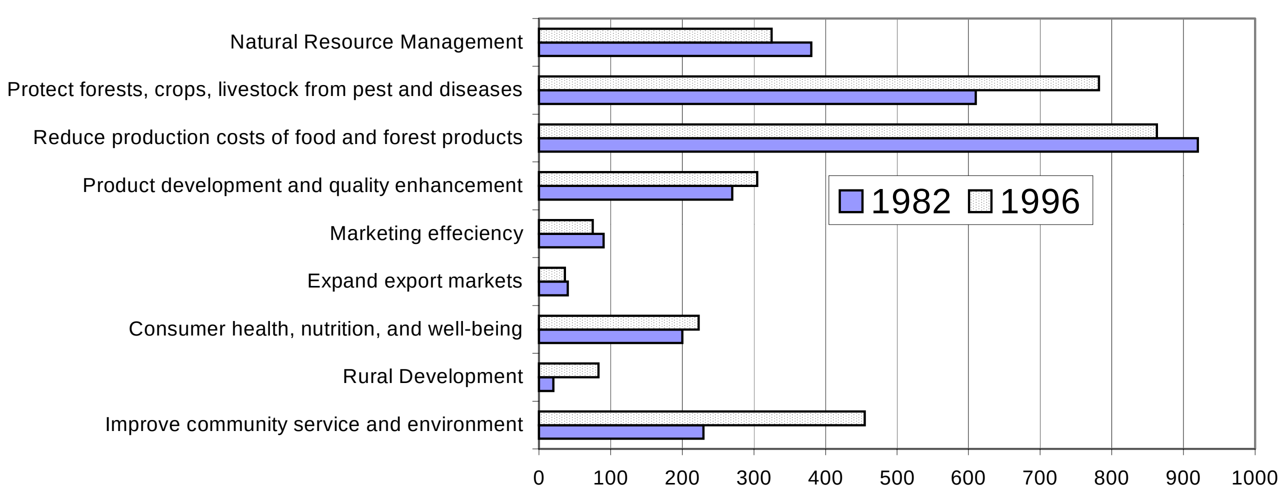


Source: Cooperative State Research Service

Funding by Goal

As shown in Figure 6, the two major goals receiving funding in the public sector are to reduce production costs and to protect crops from pests and diseases. Natural resource management receives the third largest share of research dollars. Together, these three areas make up 70 percent of all expenditures. The remaining 30 percent is split among 6 program goals, from rural development to market efficiency. Only improving community service and the environment and protecting crops from pests and diseases were significantly more important in 1996 than 1982.

Figure 6: Allocation of Public Expenditures for Agricultural Research by Goals 1982-1996

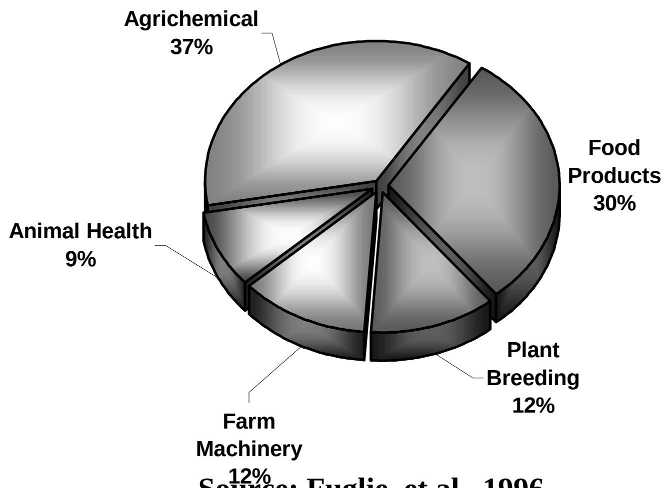


Source: Fuglie, et. al, 1996; Cooperative State Research Service

FUNDING PRIORITIES IN THE PRIVATE SECTOR

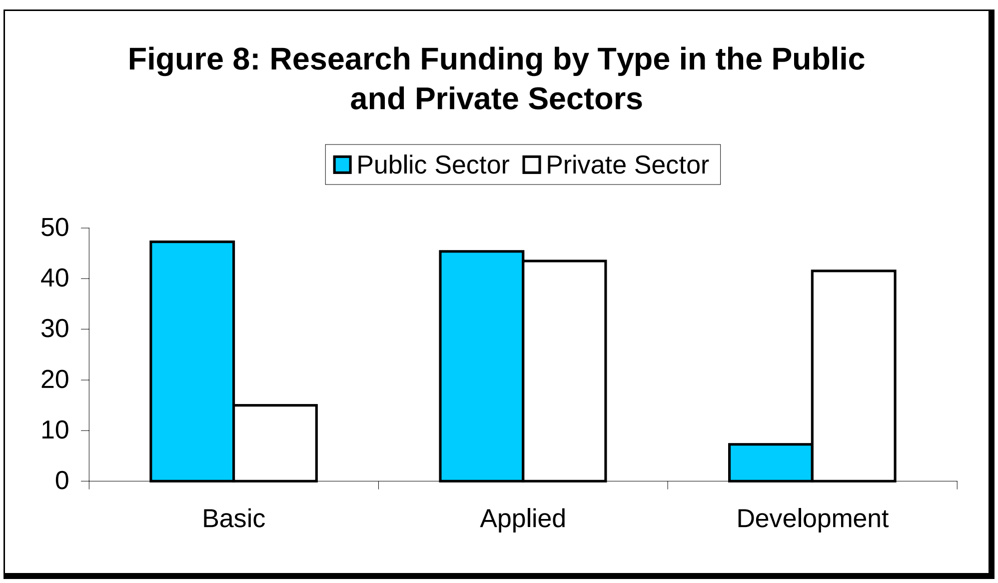
The private sector has increased research efforts over the last two decades for several reasons, including stronger intellectual property rights and protection and breakthroughs in molecular genetics, creating opportunities in biotechnology. As shown in Figure 7, the top two areas receiving research money in 1992 were agrichemicals and food products. Animal health, plant breeding, and farm machinery receive much less funding.

Figure 7: Allocation of Private Agricultural Research Expenditures by Program in 1992 ($34 Billion)



Source: Fuglie, et al., 1996

Private firms are increasingly investing in areas that were traditionally in the public domain. For example, private firms have decreased relative spending on research involving farm machinery and food products, and have increased their effort in plant breeding and agrichemicals. As shown in Figure 8, private firms still invest more in applied research and development than in basic research. About 41 percent of private research dollars are spent on product development compared to only 7 percent by government programs. Nearly half of public research is for basic research compared to only 15 percent by the private sector.



Source: Fuglie and Schimmeipfennig, 2000: p.15

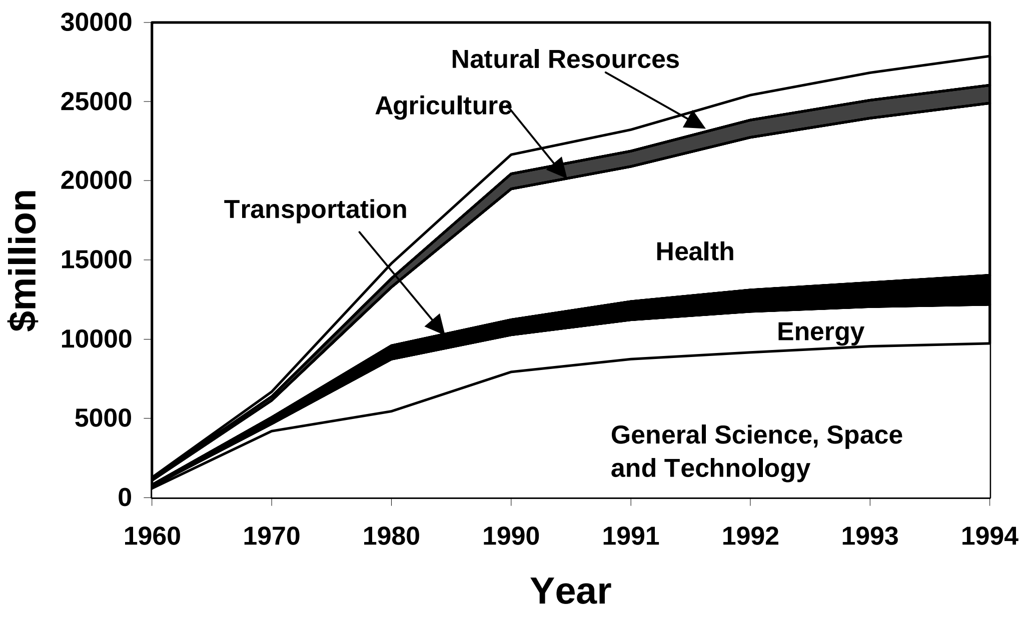
Figures for private and public expenditures are for different time periods

FUTURE FUNDING TRENDS

Public funding for agriculture has not increased in real terms since the 1970's. In 1989, the National Research Council concluded that agricultural research is underfunded. As shown below in Figure 9, the research budget for agriculture is considerably smaller than for some other research areas. This is primarily because some areas, like health, have grown very rapidly. USDA expenditures for research and development were less than 2 percent of the federal research budget ($1.5 billion of $72.7 billion) in 1997. Only about 4 percent of federal budget for university and college research was for agriculture ($408 million of $10 billion). Public funding for agriculture remains stagnant while private funding is growing.

Funding from state governments and the USDA to state agricultural experiment stations was a downward trend in the1990's. State funding fell from 55.1 percent of the Experiment Station budget in 1978 to 47.4 percent in 1994, and USDA funding fell from 22.2 to 20.3, respectively. Overall, federal support rose from 30.7 percent to 33.0 percent over that same period due to new financial resources from agencies outside the USDA. The 1990-1991 recession, declining farm numbers, and lack of political power are blamed for declining interest by state governments in funding agricultural research. Authors of studies about agricultural research are pessimistic about future support since funding is associated with large agricultural sectors and aggressive and organized farm lobbying efforts. Other reasons cited for why governments are reluctant to fund more research include spillover benefits to other constituents, long lag periods to receive returns, and difficulties in showing diffused, hard to measure benefits in order to justify expenditures.

Figure 9: United States Non-Defense Research Budget, 1960-1994



Source: Fuglie, et al., 1995 and U.S. Government Budget

THE BENEFITS OF AGRICULTURAL RESEARCH

Research benefits can be physical, economic, or social. The most common way to evaluate the physical benefits of research is through productivity (input/output ratios). The economic benefits of research are usually measured through the return on research investments. The physical and financial benefits of agricultural research have been notable. For example:

- Productivity (output per unit of input) increased on average nearly 2 percent per year for the last fifty years.
- Investment returns average 40-60 percent, higher for basic research and lower for extension education.
- Each producer feeds and clothes over 100 people.
- The average consumer spends just 11 percent of their income on food.

It is important to mention concerns about productivity and fiscal rates of return to investments in research before we discuss them in detail. A list of five major concerns is shown in Figure 10 below. Most of the concerns are about how difficult it is to measure research benefits. For example, physical and financial measures may not include costs or benefits that people care about, like a cleaner environment or better health. Investment returns might be over inflated if environmental degradation, for example, is not included, or underestimated if the benefits of improved environmental quality are not taken into account. Therefore, before moving on, we discuss two kinds of benefits from research that are neglected in productivity measures and investment return measures: social benefits and using research to answer questions.

Figure 10: Concerns about Estimating Returns to Public and Private Research

Some benefits are neglected in investment rates of return-

In principle, society should count all benefits. However, if some benefits are ignored, like environmental amenities, food safety, and better health, which are difficult to measure, society might over or under invest in research.

Market prices are an imperfect measure of social returns

Price is not always the best measure of value, and is often not available for items such as quality of life or social equity.

Private rates of return do not include spillover benefits (or costs)-

Spillovers to anyone other than the sponsor are of little interest to private firms. Therefore, private returns are usually higher than what they report.

Research needs to be maintained-

Research depreciates. An estimated 30 percent of research investment is needed just to maintain what has already been accomplished.

Benefits of research are often realized years after research was conducted-

It can take up to 30 years (especially for basic research) to realize the returns to a research investment.

Social Benefits

While the efficiency and economic gains of research are impressive, they are incomplete. Many costs and benefits go uncounted for a variety of reasons. Some are not counted because they take time to materialize. It takes an average of thirty years for agricultural research to be fully realized (Alston, et al., 1995). Hybrid corn for example took over forty years to be fully adopted. Another problem is that a portion of the benefits spill in or out to other areas. For example, U.S. tax dollars were used to improve soybean yields in countries like Brazil, which is now a major U.S. competitor. Some of the gains in these regions were not intentional, however. They "spilled out" of the United States from our research programs. Benefits spill in too. An investment of $134 million American tax dollars in Mexico and the Philippines, for example, yielded a $14.7 billion benefit through better wheat and rice varieties in the United States (Barry, 1997). This is over a 100-to-1 return on our investment. Plus, it helped people in Mexico and the Philippines. Since benefits spill in, as well as out, research in other countries or states can sometimes return high dividends to individuals or institutions that did not pay for the research.

Some benefits and costs go uncounted when they are not valued in the market. These intangible benefits (or costs) are often called non-market goods. For example, quality of life on farms is improved through better and safer equipment and chemicals. Consumers' safety and health have been greatly improved through research on processing, storage, transportation, and packaging. Research has also given us more product variety and convenience. And we all benefit from cleaner air and water. For example, 1990 crop production in the U.S. required about half as many acres as it would have in 1950. That's fewer acres of disturbed wildlife habitat, chemical spray, and soil erosion. One study (Repetto et al., 1997) estimated that productivity growth would be about 14 percent higher for agriculture if the economic value of the benefits of reduced soil erosion was added to the market benefits. Returns would likely be much higher if reduced nutrient and pesticide runoff were also included. Of course, negative impacts on the environment would have reduced the rate of return had they also been included.

Finally, social costs can also occur when there is competition for investment funds between the government and the private sector. A common investment concept is that returns should be greater than the cost of borrowed money, about 5 percent in real terms. However, Fox (1985) estimated that the pre-tax rate of return in industry was between 17.8 and 22.8 percent. Therefore, public research should earn at least this amount in order to compete.

Using Research To Answer Questions

Research can also help people make better choices about health, employment, housing, the environment, and policy simply by providing information. For illustrative purposes, Table 2 on the following page provides a current example of the kinds of information a community might consider with respect to confined swine operations. Recent improvements in technologies have revolutionized the swine industry, resulting in a transition to large, confined operations that tempt communities with jobs, income taxes, and prosperity. But what are the costs? Will there really be more jobs? Will they be good jobs? Do these megafarms drive real estate prices up or down? And what are the risks to the environment? Emotions often run high when communities confront questions like these. Research can help provide answers so that better, more informed decisions can be made.

Table 2: Examples of Questions Answered by Research: The Case of Large Scale Confinement Hog Farms and Their Potential Impacts on Communities

Economic Impact	Related Research
Productivity	• Recent gains in technology (genetics, pharmaceuticals, and transportation) have concentrated on production. Over half of hogs are produced on farms with more than 2,000 animals. Pork production per breeding animal has nearly doubled since 1965.
Employment – Quantity	• In the short run, 7-25 jobs are created, paying $14,000/year for every 1,000 sows. • In the long run, there are 14-16 jobs created for every 1,000 sows • Every job in the swine industry creates 0.25-1.25 jobs elsewhere in the community.
Employment – Quality	• Larger farms pay higher average wages (primarily from higher salaries to managers). • Larger farms provide more benefits (16% of producers provide 66% of life insurance provided by confined hog farmers). • High turnover on larger farms, 17-30%, indicates jobs might not be highly desirable. • Many jobs on large farms taken by people from outside the community • Because large farms use more technology, they employ one person for every three employed by independent producers.
Health	• 30-70% of hog industry workers complain of upper respiratory distress.
Taxes	• Hog farms pay taxes of up to $17,000 in Virginia and $8,800 in Iowa for every 1,000 sows. • There is $4,000 tax revenue for every two jobs created.
Community Services	• One new student is enrolled in school for every two new jobs. • More dust, traffic, and accidents are observed. One Iowa community spent $20,000 on gravel for traffic related to a 45,000 hog finishing operation.
Real Estate	• Real estate prices have gone up in some places from development pressure (Minnesota, Iowa) and down in others due to odor (North Carolina).
Social	• Increased efficiency helps meet an expected 20-50% higher worldwide demand for pork over the next decade. • Employment in corporate farms tends to be more culturally diverse than traditional farms, but can stress community services like schools and hospitals. • There is great debate about environmental impacts. Odor, water quality from runoff and leaching, and nitrate deposition through precipitation are all concerns. • Many small farms can generate more benefits than one big farm, but are, on average, less profitable. • Animal welfare advocates are concerned with too little space, disease, and boredom.

RATE OF RETURN TO INVESTMENTS IN AGRICULTURAL RESEARCH

Returns to Agricultural Research by Study

The returns to research have been estimated in many studies. Rates of return are the compounded financial yield from an initial investment outlay that generates a series of multiyear benefits. It is much like the yield on a bond. A detailed list of these studies can be found on the following pages in Tables 4 and 5. Fuglie, et al. (1996) summarized studies and provided an estimate of the core (most common) range of results by research and extension area as shown in Table 3 below.

Table 3: Rate of Return (%) by Type of Research Investment

Type of Research/Outreach	Full Range	Core Range
Public Research	0-100	40-60
Public Basic Research	57-110	60-90
Private Research	26-90	30-45
Extension	23-110	23-35
Farmer's Schooling	15-83	30-45

Source: Adapted from and Fuglie, et al., 1995, and ______ 1996.

The majority of these studies (1964-1993) showed an average 40-60 return to investment in public agricultural research (Table 4). Basic research earned the greatest rates of return at 60-90 percent, and extension earned the lowest at about 30 percent. The average return for public research is relatively higher than private research because the public sector conducts more basic research, which has a higher rate of return. Only about 15 percent of private research is basic, compared to over 40 percent in the public sector. There has been a general pattern of increasing rates of return from agricultural research over time. A possible explanation is the lag of agricultural research benefits, which can take up to 30 years to be fully realized. In the 1990s, most of the agricultural research benefits are due to research conducted in the 1960s and the 1970s.

Returns to Agricultural Research by Commodity

Many studies have estimated the specific returns to different commodities (Table 5). Most commodities show high rates of return, but estimates of individual commodities vary widely among studies. There is a great variation across these studies' time periods and approaches, which makes them difficult to compare. However, there is a noticeable difference between the rate of return to livestock research and crop research. Livestock returns are lower, and even negative in recent studies of extension. It is thought that research on livestock has a larger lag than research on plants due to more sophisticated characteristics and physiology of animals compared to plants.

Table 4: Aggregate Rate of Return Estimates to Agricultural Research and Extension by Study

Study	Date Study Published	Time Period	Rate of Return
			(%)
Griliches	1964	1949-1959	35-40
Latimer	1964	1949-1959	Not significant
Evenson	1968	1949-1959	47
Cline	1975	1939-48	41-50
Huffman	1976	1964	110
Peterson & Fizharris	1977	1937-1942	50
		1947-1952	51
		1957-1962	49
		1967-1972	34
Lu, Quance, & Liu	1978	1939-1972	25
Knutson & Tweeton	1979	1949-1958	39-47
		1959-1968	32-39
		1969-1972	28-35
Lu, Cline, & Quance	1979	1939-1948	30.5
		1949-1958	27.5
		1959-1968	25.5
		1969-1972	23.5
Davis	1979	1949-1959	66-100
		1964-1974	37
Evenson	1979	1868-1926	65
White & Havlicek	1979	1929-1972	20
Wait, Havelock & Otto	1979	1929-1941	54.7
		1942-1957	48.3
		1958-1977	41.7
Davis & Peterson	1981	1949-1974	37-100
White & Havlicek	1982	1943-1977	7 - 36
Lyu, White, & Lu.	1984	1949-1981	66
Braha & Tweeten	1986	1959-1982	47
Yee	1992	1931-1985	49-58
Huffman & Evenson	1989	1950-1982	41
Huffman & Evenson	1993	1950-1982	17-28

Source: Fuglie, et al., 1996; Huffman and Evenson, 1993

Table 5: Aggregate Rate of Return Estimates to Agricultural Research and Extension by Commodity

Study	Commodity	Period	Rate of Return
Benefit-Cost Approach:			
Griliches, 1958	Hybrid corn	1940-1955	35-40
Griliches, 1958	Hybrid sorghum	1940-1957	20
Peterson, 1967	Poultry	1915-1960	21-25
Schmitz and Seckler, 1970	Tomato harvester	1958-1969	16-46
Production Function Approach:			
Peterson, 1967	Poultry	1915-1960	21
Bredahl and Peterson, 1976	Poultry	1969	37
	Dairy	1969	43
	Livestock	1969	47
	Cash grains	1969	36
Evenson and Welch, 1979	Crops	1964	55
	Livestock	1964	55-60
Evenson, 1979	Technology Oriented	1927-1950	95
	Science Oriented	1927-1950	110
	Science Oriented	1948-1971	45
	Technology Oriented	1948-1971	93-130
	Farm mgmt. & ext.	1948-1971	110
Norton, 1981	Cash grains	1969	31-57
	Dairy	1969	27-50
	Poultry	1969	30-56
	Livestock	1969	56-111
	Cash grains	1974	44-85
	Dairy	1974	33-62
	Livestock	1974	66-132
Sundquist, Cheng, &	Maize	1977	115
Norton, 1981	Wheat	1977	97
	Soybean	1977	118
Smith, Norton, & Havlicek, 1983	Livestock	1978	22
	Dairy	1978	25
	Poultry	1978	61
Huffman & Evenson, 1993;	Crops	1950-1982	45-47
Evenson, forthcoming	Livestock	1950-1982	< 0-11
	Science Oriented	1950-1982	74
	Extension	1950-1982	20

Source: Fuglie, et al., 1996; Huffman and Evenson, 1993

RATE OF RETURN TO EXTENSION

The rate of returns for research is closely tied to technology transfer. The Cooperative Extension Service is primarily responsible for dispersing public research results to agricultural practitioners. County extension agents disseminate information on crops, livestock, and management practices to farmers and demonstrate new techniques as well as consult directly with farmers on specific production and management problems. Unlike research, it is reasonable to assume that extension has an immediate effect on productivity and benefits (Ahearn, et al., 1998).

Public extension expenditures, especially the federal government's share, have grown little in real terms since 1980. The bulk of extension services now come from state and county governments, and increasingly, the private sector. Private consultants also offer advice on topics such as pest and nutrient management practices. Farmers and ranchers also rely heavily on cooperatives and agricultural companies for advice on pest and nutrient management strategies. The empirical evidence on the rate of return to extension is more uncertain than for research. As shown below, estimates range from negative to over 100 percent. More recent studies (Huffman and Evenson, 1993) have found a lower rate of return to public extension than for research. A major problem in estimating the rate of return to extension is data-related. The data reporting system for public extension expenditures is less complete than for research expenditures. Nevertheless, Huffman and Evenson (1993) suggest that farmer schooling (high school and college education) is a good substitute for extension, perhaps accounting for the lower returns to extension. That is, farmers increasingly can go directly to scientists and other experts and do not need extension intermediaries to digest and summarize information as much as they used to.

Returns from extension in livestock are negative. This could be a measurement problem. However, if true, it could signal that society invested too much in livestock extension. Political pressure for help from threatened industries could explain an over expenditure, as the beef industry went through periods of rapidly declining prices. At the same time, the private sector financed more research in expanding industries such as poultry and swine, and these firms generally utilize their own resources for technology transfer.

Table 6: Average Rates of Return (%) to Extension by Study and Commodity

Study	Period	Annual Return to Extension
Huffman, 1976	1964	110
Evenson, 1979	1949-1971	110
Huffman, 1981	1964	110
Lu, Quance & Lui 1978[a]	1939-1972	25
Lu, Cline & Quance, 1979	1939-1972	24 – 31
Evenson, unpublished	1950 – 1982	82-101
Huffman and Evenson, 1993		
Average	1950-1982	20
Extension in Crop sector	1950-1982	41.6
Extension in Livestock Sector	1950-1982	negative

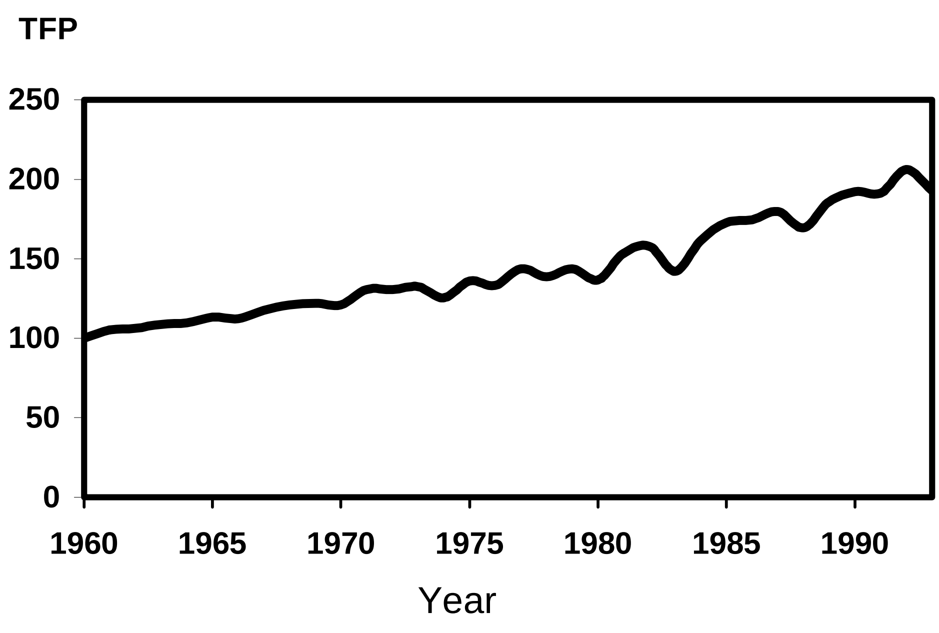
Source: Adapted from Fuglie, et al., 1996; Huffman and Evenson, 1993
[a] Combined research and extension

PRODUCTIVITY GROWTH IN THE UNITED STATES

Productivity captures the relationship between outputs and inputs in production. It is most commonly expressed as *Total Factor Productivity* (TFP), which is a ratio of total outputs, measured in an index form, to total inputs, also measured as an index. If the ratio of total outputs to total inputs is increasing, more outputs can be obtained for a given level of input.

Figure 11 below shows the strong productivity growth that the United States has experienced over the last 30 years. TFP has nearly doubled from 1960 to 1993 because the value of farm outputs nearly doubled, while input usage decreased by 10 percent. The details about productivity growth are given in Table 7 on the facing page. The rate of growth in productivity is divided between the rate of growth in outputs and the rate of growth in inputs, weighted by the commodity prices and costs. Furthermore, productivity estimates for output are divided into “crops” and “livestock and livestock products.” The value of livestock products increased by 50 percent while crops increased around 100 percent. Inputs can be divided into materials, labor, and capital. There was a 33 percent increase in materials used, a 58 percent decrease in labor and a 7 percent decrease in capital use.

Figure 11: Total Factor Productivity for Agricultural Output in the United States,1960-1993



Source: Adapted from Ahearn, et al., 1998 (U.S.)

Table 7: United States Farm Output, Input Use, and Total Factor Productivity, 1960-1993

Year	Total Farm Output	Livestock and L. Products	Crops	Total Farm Input	Material	Labor	Capital	Total Factor Productivity TFP
1960	100	100	100	100	100	100	100	100
1961	102	104	101	97	98	97	98	105
1962	103	105	102	97	99	96	97	106
1963	107	108	105	98	102	94	97	109
1964	106	111	102	96	101	88	98	110
1965	108	108	108	95	101	87	98	113
1966	108	110	107	96	108	81	99	112
1967	112	113	112	96	109	76	102	118
1968	114	113	115	94	106	73	103	121
1969	115	113	118	94	110	72	103	122
1970	115	118	113	95	111	72	103	121
1971	123	119	126	94	109	70	104	131
1972	124	121	126	94	112	69	103	131
1973	128	122	135	97	115	70	107	132
1974	121	120	124	96	117	64	110	125
1975	129	114	141	94	113	64	111	136
1976	131	119	140	98	119	64	112	133
1977	139	122	153	96	117	61	114	144
1978	141	122	157	102	133	58	114	139
1979	150	124	172	104	141	57	116	144
1980	145	129	157	106	144	55	118	137
1981	159	131	180	103	136	55	118	154
1982	159	130	182	100	131	54	116	158
1983	139	134	142	97	132	52	110	142
1984	157	131	177	97	128	52	112	161
1985	163	135	186	94	125	48	110	173
1986	159	136	175	91	122	46	105	175
1987	161	139	178	89	123	45	100	180
1988	151	142	156	89	122	48	98	169
1989	163	143	179	88	121	46	97	186
1990	172	145	192	89	126	46	97	192
1991	172	149	190	90	128	46	96	191
1992	183	151	208	89	128	45	95	206
1993	172	153	185	89	133	42	93	193

Compound annual average of growth rate:

1960-1993	1.72	1.28	2.22	-0.33	0.91	-2.49	-0.19	2.09
1960-1970	1.32	1.53	1.18	-0.42	1.01	-2.96	0.25	1.77
1971-1980	2.37	0.95	3.61	1.05	2.71	-2.53	1.44	1.36
1981-1990	1.98	1.16	2.89	-1.69	-1.27	-1.69	-1.99	3.70
1991-1993	0.13	1.86	-0.89	0.00	1.86	-3.30	-1.19	0.32

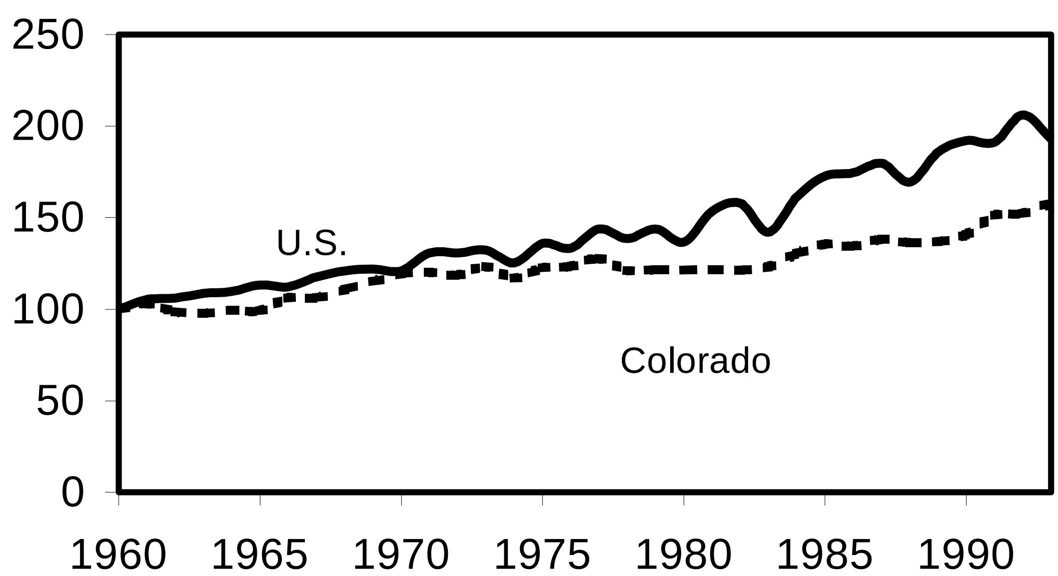
Source: Adapted from Ahearn, et al. 1998

PRODUCTIVITY GROWTH IN COLORADO

Table 8 on the facing page shows how total factor productivity changed in Colorado from 1960 to 1993. TFP in Colorado as compared to the United States is shown below in Figure 12. Overall, Colorado did not share the same growth rate as the U.S. average, though it did very well. The total value of farm output (aggregate crops and livestock) showed a better performance in Colorado than in the U.S., but input costs did not fall as much in Colorado as they did nationwide. Livestock output climbed faster in Colorado, while the crop sector in Colorado lagged behind the U.S. It is not surprising that livestock research was above average in Colorado since cattle is the State's number one commodity. In addition, crop research in the state is highly subject to spilling out to other states since most of our major crops, such as wheat and corn, are produced in an area much bigger than the state.

Differences between growth rates in Colorado and nation in Figure 12 are most likely due to the composition of agriculture in Colorado. Some of the major agricultural states, like Iowa, had slower growth rates than average, while some of the minor agricultural states, like Delaware, had higher than average growth rates. This occurred because it is more difficult to improve efficiency in farming areas that are already big and productive than where agriculture is relatively smaller and less important. Input levels in Colorado have not fallen as much as they have nationally, while output levels have increased commensurately. The labor index fell by 31 in Colorado between 1960 and 1993 but fell by 58 nationwide over the same period. Likewise, the materials index rose by 88 in Colorado compared to 33 nationally. Capital use is about the same. Finally, because of spillovers from one state to another, as described in Figure 10, the national average is probably the most appropriate measure of productivity.

Figure 12: Total Factor Productivity for Agricultural Output in Colorado and the United States



Source: Adapted from Ahearn, et al., 1998 (U.S.); Ball and Nehring, 1998 (Colorado)

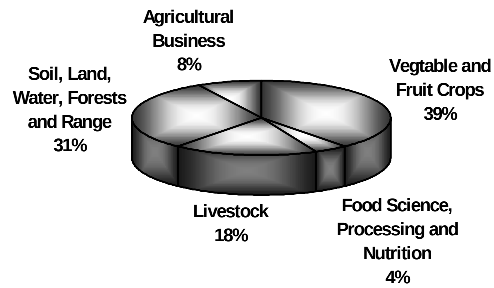
Table 8: Colorado Farm Output, Input Use , and Total Factor Productivity, 1960-1993

Year	Total farm output	Livestock and livestock products	Crops	Total farm input	Materials	Labor	Capital	Total factor produc-tivity
1960	100	100	100	100	100	100	100	100
1961	104	109	97	101	103	96	99	103
1962	104	118	86	106	113	97	98	99
1963	102	124	75	104	113	92	97	98
1964	102	123	76	103	112	88	97	100
1965	106	134	71	107	120	87	97	99
1966	117	142	88	111	128	87	99	106
1967	124	159	81	117	138	87	102	106
1968	127	155	92	115	132	90	103	111
1969	143	177	102	125	153	89	102	115
1970	156	193	110	131	166	89	102	120
1971	171	219	108	142	189	87	105	120
1972	174	229	100	146	200	85	104	119
1973	162	203	109	131	167	89	106	123
1974	141	175	97	121	140	104	108	117
1975	152	181	113	124	149	98	108	123
1976	158	186	118	128	160	89	110	123
1977	171	207	122	134	174	86	111	128
1978	181	221	125	149	205	83	112	121
1979	175	199	147	144	195	80	112	122
1980	175	193	159	144	193	85	114	121
1981	163	170	163	134	169	91	113	122
1982	165	179	155	136	183	75	112	121
1983	168	180	160	136	187	80	107	123
1984	176	186	171	135	183	78	107	130
1985	184	188	190	136	179	95	106	135
1986	182	198	169	135	186	86	102	135
1987	185	199	175	134	184	95	97	138
1988	186	203	169	136	193	86	96	136
1989	180	197	163	131	182	88	95	137
1990	186	199	178	132	187	81	94	141
1991	187	200	179	124	173	74	92	151
1992	193	210	177	127	181	71	93	152
1993	205	224	186	129	188	69	92	158
Compound annual average of growth rate:								
1960-1993	0.02	0.03	0.02	0.01	0.64	-0.13	0.03	0.23
1960-1970	0.04	0.07	0.01	0.03	0.24	-0.10	-0.01	0.04
1970-1980	0.02	0.02	0.04	0.02	0.75	-0.11	0.08	0.22
1980-1990	0.01	0.00	0.02	-0.01	0.84	-0.14	0.06	0.29
1990-1993	0.03	0.03	0.03	0.00	0.82	-0.26	-0.07	0.51

Source: Ball and Nehring, 1998

Research supported by the Agricultural Experiment Station (CAES) at Colorado State University supports the public research priorities described in Figures 5 and 6. As shown in Figure 13, commodity research on crops and livestock, plus research on natural resources, garners nearly three-quarters of the CAES funding. Agricultural business and food science, processing and nutrition share the remaining quarter.

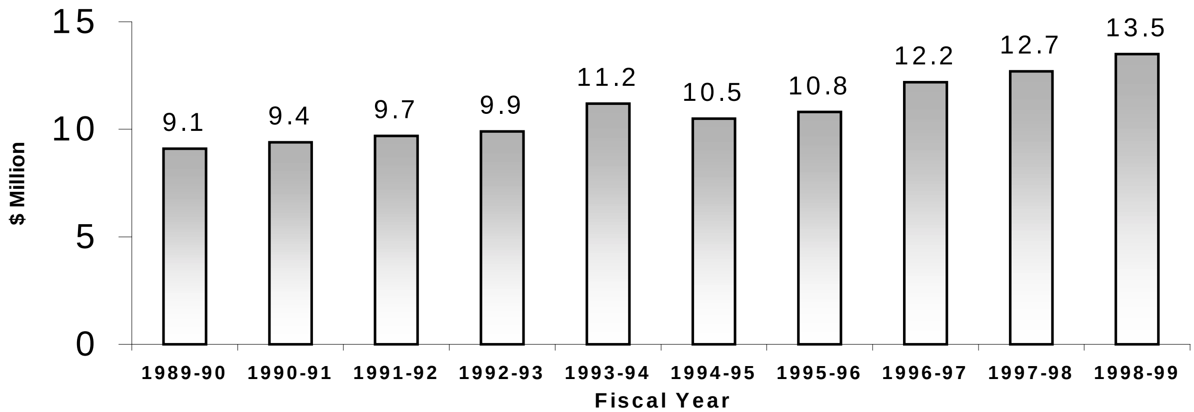
Figure 13; Colorado Agricultural Experiment Station Research Research Expenditures by Program in 1998-1999



Source : The Fact Book 1998-1999 - Budget and Institutional Analysis - Colorado State University

Basic research is conducted in a variety of disciplines related to the biology of plant and animal growth and the properties and processes in the natural resources (soil, water, vegetation, and air). Both pre-technology and applied research are conducted on plant and animal production systems involved in agricultural commodities. These studies involve applying knowledge to problems in producing commodities as well as in related areas of marketing, agricultural policy, and nutrition. Product development is a minor component of the CAES research portfolio. The CAES typically supports about 130 separate research projects conducted in on-campus departments and at off-campus research centers. These projects can be classified as follows: 33% basic research; 60% applied research, and; 7% product development. It is essential that a portion of the research program focus on basic research to generate the knowledge needed to solve future problems in agriculture and natural resources. At the same time, solving problems of today's producers, managers, and consumers is also essential. As shown in Figure 14, spending has grown from $9.1 million to $13.5 million over the last 10 years.

Figure 14: Colorado State Experiment Station Research Expenditure



Source : The Fact Book 1998-1999 - Budget and Institutional Analysis - Colorado State

Examples Of The Return On Investment For CAES Programs.

- Development of pest resistant wheat – the Russian wheat aphid (RWA) entered Colorado in the mid 1980’s and immediately caused significant reductions in the yield of hard red winter wheat. The losses were estimated in the $15-25 million range per year. Through increased funding from the Colorado legislature, promoted by the wheat industry, the wheat improvement program in the CAES redirected efforts to incorporate genes conferring tolerance to the RWA into wheat adapted to the growing conditions in the Great Plains using conventional plant breeding techniques. The first RWA tolerant wheat was named Halt and was released in 1996. The total investment in development of the new wheat was approximately $10 million. This total investment was recovered in the first year of adoption because 1) yield losses of approximately $15 million were eliminated and 2) reducing insecticides saves growers millions more. In addition, reduced insecticide use is a benefit to the environment. Additional wheat varieties tolerant to the RWA have subsequently been released by the CAES program and are being planted by growers.

- Integrated resource management (IRM)– an interdisciplinary program was established to address issues faced by ranchers involved in beef and sheep production. It was commonly assumed that birthing and rearing a 100% calf or lamb crop was the key to maximizing profits in ranch operations. The IRM team involving specialists in animal reproduction, range management, animal nutrition, veterinary medicine, and economics has worked cooperatively with numerous ranchers throughout Colorado to analyze their livestock production practices, the resources available, and ranch economics. In essence, the analyses indicated that factors other than reproduction most often limited ranch profitability and that a detailed analysis of each individual operation is a key to maximizing profit. A simple, uniform solution does not exist for the problem of ranch profitability.

- Dryland cropping systems – In 1985, a series of experiments were established in eastern Colorado to evaluate cropping systems as alternatives to the wheat-fallow system. Earlier work had shown that the wheat-fallow system was inefficient in storing moisture, the key factor to crop production in the Great Plains. A wheat-corn-fallow system using reduced tillage practices was shown to increase total crop yield and to increase profit for the northern 2/3 of the eastern Colorado plains. Dryland corn production has significantly increased in the past 5 years and now exceeds 200,000 acres. The differential between wheat and corn in terms of yield and price indicates that changing from a wheat-fallow to wheat-corn-fallow system results in an $5 million-per-year gain to Colorado’s economy. Furthermore, the total cost of the long-term research program was recovered in a single growing season!

The above are three examples where the economic benefit of CAES programs can be predicted. Many other CAES programs have a positive economic benefit to the agricultural community as well as to the consumer.

CAUTIONS AND INTERPRETATIONS

While the productivity of American agriculture seems to be phenomenal and appears to justify public and private investments in research, several cautions and qualifiers should be considered before making final interpretations. Returns, for example, could be higher or lower than reported. Two studies that considered lagged time between investment and benefits revised average returns downward from about 60 percent to 30-35 percent. However, another study found that the environmental benefits from reduced soil erosion increased returns by 14 percent. There is little doubt that many costs and benefits have been omitted. Some of the major limitations to studies about research returns are discussed below.

Measurability
It is difficult to measure the returns to research for many reasons. First, many costs and benefits are hard to observe or measure. For example, the health costs of using pesticides, environmental degradation, or physical, emotional, and financial difficulty associated with the displacement of labor or shifting cropping patterns associated with agricultural research are not included in figures about the returns to research or productivity. Many benefits are missed as well, such as better health or a cleaner environment. Second, costs and benefits can be missed because they are difficult to disaggregate. The most important examples here are the contributions of research versus extension or public versus private research. Finally, costs and benefits can be missed because they occur in other regions.

Forecast Error
An important assumption thus far is that the past is a good predictor of the future. Just because returns were 60 percent does not mean they will continue at that level. A very important forecasting factor for agriculture is international trade. Trade expands our market for outputs, increasing the returns to research because there is reduced pressure for prices to fall from excess supply. Forecasting price changes can be difficult for most research.

Time Lags on Returns
The benefits of research can take as long as thirty years to be fully realized. On average, most benefits we observe today are probably from investments made 10, 15 or 30 years ago. Benefits that take longer to accrue are discounted more heavily because future dollars are worth less than current dollars, due to compound discounting.

Distribution of Costs and Benefits
The most obvious problem regarding the distribution of benefits is spillovers. Spillovers occur when investments paid for in one region are realized in another. Another important assumption about the estimates provided here is that distribution across social class does not matter. Displacing labor, giving more to the rich than the poor, or less to minorities is not considered. In addition, the distribution to consumers, taxpayers, and producers does not matter.

Competition With Private Firms
Finally, many people have pointed out that government investments should not restrict private investments. Taking income away through taxes to fund public research excludes private research. Fox (1985) suggested that returns should exceed private rates of 18-20 percent to assure this does not happen. In a later study, he showed that the efficiency loss from government could reduce returns by 10-23 percent compared to the private sector.

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