THE BENEFITS OF PUBLIC INVESTMENT IN AGRICULTURAL RESEARCH FROM A US PERSPECTIVE

Kelly Day Rubenstein,* Paul W. Heisey and John L. King. Economic Research Service, U.S. Department of Agriculture, Washington, DC, USA

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Agriculture is a science-based industry. Nearly all productivity improvements are the result of research and development (R&D), whether they be mechanical (e.g., farm equipment), biological (e.g., plant and animal varieties) or management-related (e.g., integrated pest management). Individual agricultural producers are unlikely to reach the scale of production needed to recover R&D costs, which means most of the science applied to agriculture is developed by public research institutions or private companies.

Much of the science used in agriculture comes from the life sciences. Plant and animal varieties need resistance to pests and diseases, and tolerance to non-biological stresses such as drought and heat. Some stressors can be managed physically or chemically (e.g. irrigation or crop protection with pesticides). Even in these cases, understanding the biological basis of how plants, animals, and pests will respond is essential to efficient management.

Resources devoted to research

The U.S. has a federal-state agricultural research and extension system, with a long history of collaboration with the private sector. The upper portion of the flow chart (Figure 1) shows the level of funding by each group: the private sector leads, followed by the federal government and the States. The lower portion shows who conducts the research. Federal-level research generally addresses issues of national importance (about $1.3 billion). State-level research ($3.7 billion) may be regionally applicable, though research at academic institutions may be broad in scope. Private sector research ($6 billion) is often nearest to the marketplace (in the U.S. over half the private research is performed by the food sector). The system is characterized by numerous linkages between institutions.

Over the past 40 years, U.S. agricultural R&D has increased and now totals $11 billion in inflation-adjusted dollars. Advances in the biological sciences (beginning with hybridization in the 1930s) and stronger intellectual property rights (IPRs) have stimulated private sector effort in R&D, which now exceeds that of the public sector. Since about 1980, public agricultural research funding has been essentially flat in real terms, except for a brief period of increase in the early 2000s (Figure 2).

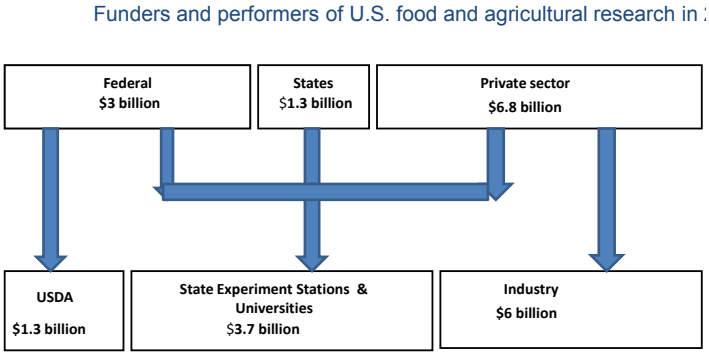

Figure 1

Source: Public R&D data from USDA-CRIS and NSF and available from ERS; private R&D data from Fuglie *et al*, forthcoming.

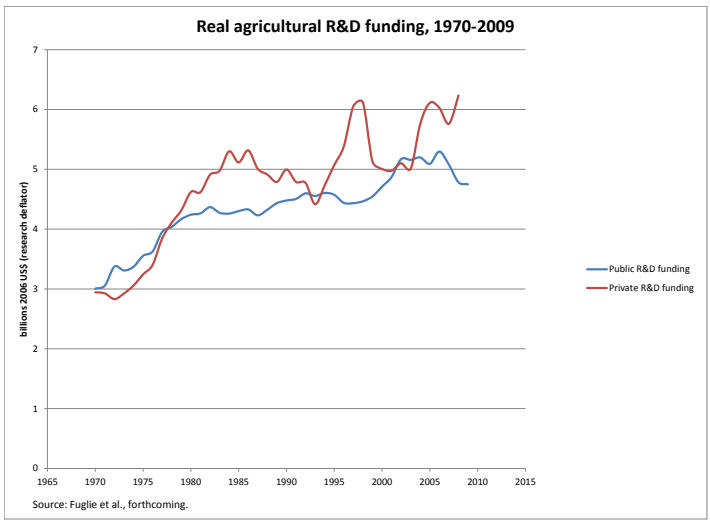

Figure 2

The nature of public research

Historically, U.S. public institutions played a direct role in developing new technologies and encouraging their commercialization and adoption by farmers. Research in production agriculture (e.g., plants and animals) still accounted for 53% of total public research in 2009, a slight decrease from 56% in 1998. Even when corrected for inflation, plant-related R&D increased between 1998 and 2009.

*Kelly Day Rubenstein: Resource, Environment and Science Policy Branch, USDA Economic Research Service, 355 E St., SW, Washington, DC 20024; 202-694-5515; kday@ers.usda.gov. The views expressed are the authors' and do not necessarily represent the views of the Economic Research Service or U.S. Department of Agriculture

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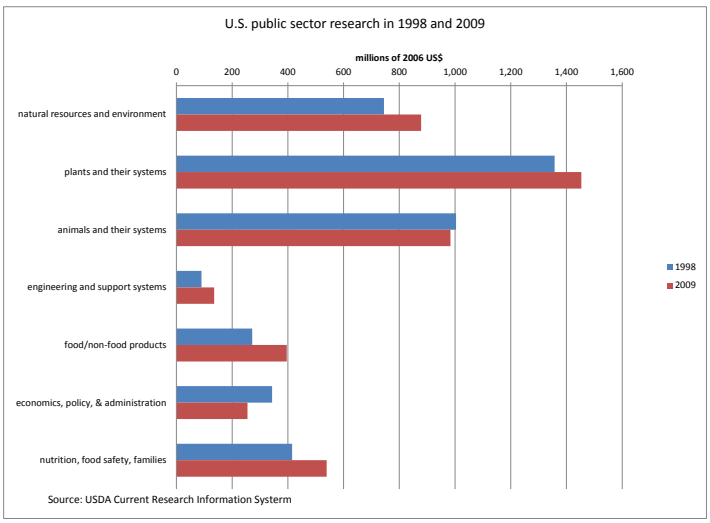

Figure 3

A comparison of public research funding in 1998 and 2009 reveals that U.S. public sector research has shifted R&D emphasis toward social and environmental goals. The areas of public research with the largest growth are natural resources and the environment, human nutrition and food safety, and the food/non-food processing area (Figure 3). The latter category includes biofuels and use of waste and underutilized co-products. All three areas address public goals for which there are limited financial incentives for private R&D. As the private sector has grown in importance as a source of market and near-market technologies, public research has gradually shifted from more applied research to research addressing non-market goods.

Pest management research

In 2009, U.S. spending on public R&D related to plant protection equaled $521 million, or $473 million in 2006 dollars. This total refers specifically to research categories directly concerned with plant protection (such as integrated pest management (IPM) or insects affecting plants). It does not include research on plant biology, plant breeding, or plant systems. Plant protection accounts for about a third of all plant research, and approximately 12% of all public agricultural research. The largest categories are research on pathogens affecting plants and research on insects affecting plants, followed by research on weeds, biological controls, IPM and vertebrates affecting plants.

In 2009, the U.S. private sector spent $672 million (in 2006 dollars) on agricultural chemicals research, including herbicides, insecticides, fungicides, and plant growth regulators. Agricultural chemicals research is the private research category most closely related to plant protection. This is 17% of the total amount invested by the private sector in agricultural input research. It does not include research on fertilizers, a category with relatively limited private research investment within the industry. Agricultural chemicals research was the third largest investment in agricultural input research made by the private sector, following research in crop seed/biotechnology and farm machinery. A large proportion of private sector research into crop seed/biotechnology could be considered plant protection research, although it is hard to separate out the exact proportion.

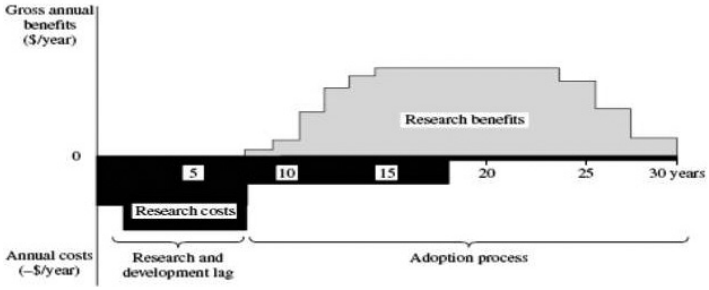

Figure 4

The research process

When an institution invests in a new technology (such as a new crop variety with disease resistance) it typically incurs research costs over several years working to develop it (Figure 4). After the technology is successfully developed, benefits begin to accrue to the institution in sales revenues and to growers in the form of higher yields and lower production costs. But after some time, the technology eventually goes out of use, either because competing products replace it or because the technology loses effectiveness (due to disease overcoming resistance in the variety, for example).

The research costs over this cycle can vary, particularly amongst different types of research. Economists have used regression models to determine the average lag associated with agricultural research undertaken by the public sector in the U. S. They also seek to determine how long this research contributes to productivity growth until it becomes obsolete. As more data have accumulated on agricultural research and growth, it has become possible to develop more sophisticated models on the statistical relationship between these variables. Current research on this topic suggests that, on average, public agricultural research undertaken today will begin to influence agricultural productivity noticeably in as little as 2 years. However, 10–15 years is thought to be a more typical research lag. There is some evidence that lags are even longer. Alston *et al.* (2010) find that some research investments continue to contribute benefits 35–50 years after the initial investments have been made. Research lags are longer for some types of research than for others. For example, they are likely to be longer for more basic research than they are for more applied research.

In the specific case of plant breeding, the USDA (1990) stated that it may take from 8 to 11 years to develop a new crop variety. More recently, the use of molecular markers has allowed breeders to increase the rate of genetic gain in desired traits (Eathington, *et al.* 2007). Even using genetic engineering to incorporate a desired trait, Monsanto (2011) estimates lags anywhere from six to 13 years between identification of the gene or trait and market launch of a product. In the case of crop protection chemicals, a survey of large firms indicates that on average approximately 8–10 years elapse between initial synthesis of a chemical and its commercial introduction (Phillips McDougall, 2010). Even this relatively long period does not include the length of investments prior to initial

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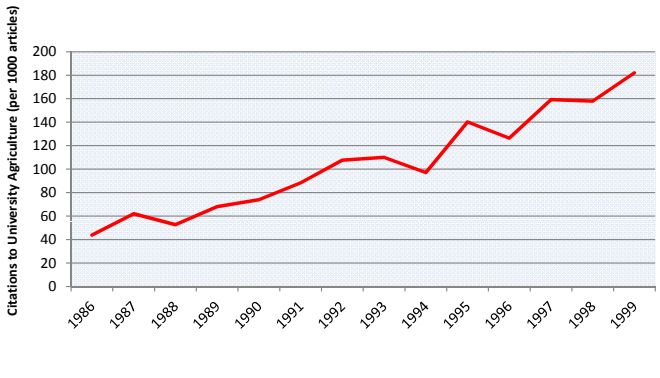
synthesis, or the time necessary for benefits to reach customers when initial adoption rates are low.

Returns to agricultural R&D

Economic assessments of payoffs from public investments in agricultural research have attempted to determine the "social rate of return" to these expenditures. This is reported as a percent return on each dollar spent on research. The return is "social" because it includes all of the economy-wide benefits from higher productivity. These returns benefit not only farmers but also the food industry and consumers, who gain from more abundant and lower cost commodities. As a benchmark, social returns to public expenditures are often compared with the return to U.S. treasury bonds as a measure of the opportunity cost of public funds. Historically, the inflation-corrected return on U.S. government securities has been around 3–4% per year.

Against this benchmark, economic studies find that public expenditures on agricultural research have yielded real returns several magnitudes higher. Some of these studies have estimated returns to research on particular commodities or in particular States. Several have assessed returns to investment in the Federal-State public agricultural research system as a whole, for various periods of the 20th century. For 35 studies published between 1965–2005 (Huffman & Evenson, 2006), the median estimate of the social rate of return was 45% per year. As a rough approximation, this implies that each dollar spent on agricultural research returned about $10 worth of benefits to the economy. Although these studies have produced a range of estimates of the rate of return to agricultural research (estimates are sensitive to methods and assumptions), they all agree that the return to public agricultural research has been significantly higher than alternative investments yielding the same returns as Federal securities. This is true even though a sizeable share of research undertaken may never be applied to technology developments that are adopted by farmers and despite the long lags between some research expenditures and their benefits.

Another, more direct means of demonstrating the benefits of public agricultural science is its role in raising private R&D productivity. Private firms are free to draw on published agricultural research, to advance their R&D objectives. Analysis of agricultural science journal publications indicates a majority of these are written at publicly supported universities, and citations to "open science" are increasing among private firms that publish their own research (Figure 5).



Source: ERS analysis of NBER-Rensselaer Polytechnic Institute Scientific Papers Database

Figure 5 Citations to university agricultural science by select private firms, 1986–1999

Measuring benefits from R&D

Analysts from many different disciplines, including economics, have applied a wide variety of tools to the evaluation of scientific research. Looking at available methods for research evaluation, several primary types emerge:

• Peer Review

Peer review is the most widely applied method of Federal research evaluation. Peer review is critical to monitoring and improving the scientific content of Federal research, but it may not provide complete information concerning market acceptance of technologies or ultimate social benefits flowing from Federal research.

• Econometric and Economic Surplus Analysis

Standard tools of economic evaluation such as econometric or economic surplus analysis have usually been applied retrospectively. They have also been most frequently used to analyze economic impacts at more aggregated levels than that of a single research project.

• Bibliometric techniques

Bibliometrics count research publications and analyze citation patterns, such as the citation-productivity analysis described above. Problems with bibliometric analysis can include difficulty setting objective standards. Bibliometric methods are not well suited to assessing current research projects, since citations lag publication, and publication lags discovery and achievement.

• Economic Reasoning in the Absence of Formal Methods

A principal economic justification for public research is market failure in the creation of knowledge. One of the most fundamental contributions of an economic perspective is a more precise characterization of the concept of "market failure." Economic analysis can help to depict the nature of the market failure that public research needs to address. Understanding the nature of the market failure addressed by research cannot only provide justification for past investments, but also help target future research spending.

Various problems complicate efforts to assess research programs and projects. In addition to the issue of long and variable lags that increase the difficulty of linking benefits and costs, accurate assessment of public research benefits can be limited by non-market benefits and attribution issues.

• Basic research and non-market goods

As would be expected, measuring research impacts is more difficult when important research benefits are non-market. In Federal research evaluation, benefit-cost analysis has been used primarily for Federal research programs that produce specific, near-market technologies. Research producing significant non-market benefits (for example environmental or

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health-related research), or basic research with no immediate market applicability, is much more difficult to measure.

• Attribution

Proper attribution of research results is particularly important for economic research evaluation, and attribution issues are considerably more complex than simply identifying potential sources of the research in question. Research builds on previous findings, and related research is often being performed by other institutions. Attributing benefits to one group of researchers is imprecise at best.

Conclusions

The U.S. agricultural research system illustrates many of the complexities that characterize research systems worldwide. Measuring the benefits of agricultural research is subject to many methodological and practical difficulties, in part because of the multiplicity of research institutions and in part because public goods outputs of research institutions are inherently difficult to discern. Individual research projects and programs pose more complexities for measurement than agricultural research taken as a whole. When R&D is aggregated, the payoffs to public agricultural research are large, and these payoffs have been confirmed in most of the studies that have addressed the issue. Public agricultural research is also complementary to private research – in other words, it tends to raise returns to private research. Thus, reductions in investment in public agricultural research may lead to lower growth in agricultural productivity, higher prices for agricultural products, and elevated environmental costs as pressure to expand cropland would intensify. The complementarity between public and private agricultural research means private research institutions would find it increasingly difficult to fill the gaps left by lower public investment. Furthermore, in addition to the indirect contribution of public research to reducing environmental damage by raising agricultural productivity, public research is also more likely to address directly research topics in the areas of environmental protection and nutrition-related human health.

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Kelly Day Rubenstein is an economist with the Resource, Environmental and Science Policy Branch at the Economic Research Service, USDA. Her research focuses on economic aspects of agricultural research and development, public research policy and the role of genetic resources in the agricultural production process.

Paul W. Heisey is an economist in the Resource, Environmental, and Science Policy Branch at the Economic Research Service, USDA. His work focuses on agricultural science policy, in particular public and private sector agricultural research and development, intellectual property, and genetic resources. Previously he was an economist with the International Maize and Wheat Improvement Center (CIMMYT) in Pakistan, Malawi and Mexico.

John L. King is an economist in the Resource, Environmental and Science Policy Branch at the Economic Research Service, USDA. His research focuses on public and private research in agriculture, and developing tools and best practices for measuring the impact of public sector science policies.

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