



Investing in a Better Future through Public Agricultural Research

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Introduction

Population and income growth translates into rapid growth in the demand for high-valued food—e.g., meat, fish, fresh fruits, and vegetables—and for feed for livestock.

The U.S. and world populations are expected to grow by approximately 30% by the year 2050, and world real income per capita is expected to grow by 98% (Nelson et al. 2010). Population and income growth translates into rapid growth in the demand for high-valued food—e.g., meat, fish, fresh fruits, and vegetables—and for feed for livestock. These changes will place increasing demands on arable land and freshwater. Moreover, climate change threatens to shift the comparative advantage for crop and livestock production farther away from the equator and toward more northerly areas in the Northern Hemisphere as well as to increase the variability of local weather conditions. Although agricultural productivity growth during the last two decades of the twentieth century was sizable in developed countries and in some developing countries, they built on past investments in agricultural research. Worldwide and in the United States, however, investments in public agricultural research have slowed since 1980 (Huffman and Evenson 2006a; Pardey et al. 2006). In the United States during the same period, private agricultural research and development (R&D) has been growing significantly faster than public agricultural research (Alston et al. 2010; Huffman and Evenson 2006a). As in the case of other global public goods such as the mitigation of air and water pollution, the full social costs of dramatically reduced funding of public

American agricultural technologies, although less environmentally polluting than in the 1970s, continue to cause soil erosion and air and water quality problems and use substantial amounts of fossil fuels.

New projections suggest that the long-term downward trend in real-world food prices is past; from 2010 to 2050 the real-world prices of corn, wheat, and rice are expected to increase an average of 1.4 to 2.5% per year under a baseline scenario, and by roughly half this rate under the most optimistic scenario.

World over, living standards depend on the availability of resources and how efficiently those resources are used. Agriculture, of course, is similarly constrained.

agricultural research recently could take many years to become fully apparent. But the effects will last for decades and might be difficult to reverse. Plans for a better future must start today.

American agricultural technologies, although less environmentally polluting than in the 1970s, continue to cause soil erosion and air and water quality problems and use substantial amounts of fossil fuels (CAST 2010a; Keystone Alliance for Sustainable Agriculture 2009). Disease-producing organisms and other pathogens continually evolve and threaten past advances in crop and livestock productivity so that science and technology are hard pressed to maintain, let alone increase, future agricultural productivity. At the same time, some special interest groups, particularly NGOs, call for farm output-repressing limitations on commercial fertilizers and pesticides, genetically modified organisms, and housing requirements of farm animals.

Whether worthy or not, these types of restraints will raise food prices unless offset by improved agricultural technologies. Consumers have enjoyed the economic benefits of declining food prices during the twentieth century, and from 1948 to 1996 the real price of food at home declined at an average rate of 1% per year (Huffman 2011a). Farm commodity prices, however, have been quite volatile during the period from 2007 to 2011, spiking in mid-2008, then falling before spiking again in late 2010 and early 2011, driven in large part by volatility in fuel costs. New projections suggest that the long-term downward trend in real-world food prices is past; from 2010 to 2050 the real-world prices of corn, wheat, and rice are expected to increase an average of 1.4 to 2.5% per year under a baseline scenario, and by roughly half this rate under the most optimistic scenario (CAST 2010b; Nelson et al. 2010; Tweeten and Thompson 2009). These changes in circumstances reflect anticipated growth in population and per capita incomes, climate change, climate change mitigation, and emphasis on biofuels.¹ This report addresses likely future changes in U.S. agricultural supply and how investments in public agricultural research can improve the future well-being of residents of the United States and the world.

Beneficiaries of Agricultural Research

World over, living standards depend on the availability of resources and how efficiently those resources are used. Agriculture, of course, is similarly constrained. Stated in economic terms, the flow of farm outputs Q depends on the flow of inputs under the control of farmers X and on the productivity of those inputs T . Farm outputs Q consist of crops and livestock produced and their products. The flow of production inputs consists of land services, labor, capital, water, and materials, including fuel, seed, agricultural chemicals, feed, and the like, often referred to as conventional inputs. At the aggregate level, the relationship among these variables can be summarized roughly as $Q = T \cdot X^\beta$. β is a parameter that is a positive number, generally close to 1. If β is 1, then productivity, sometimes referred to as total factor productivity, is summarized by $T = Q/X$. If additional output requires an equally proportional increase in conventional inputs (X), then T is unchanged. United States agriculture, however, has a record for more than a century of Q growing faster than X , i.e., agricultural productivity is increasing.

How can this happen? Other inputs, notably nonconventional inputs such as public and private research, university extension, farmers' education, and public

¹ For example, in the United States the Energy Independence Act of 2007 mandates the production of 136 billion liters of renewable fuels by 2022, including 79 billion liters of advanced biofuels and cellulosic ethanol (CAST 2010a).

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infrastructure, must increase and thereby raise agricultural productivity. Indeed, in the six decades since 1948, U.S. Department of Agriculture (USDA) estimates show that U.S. farm output increased by an average of 1.58% per year, inputs under the control of farmers increased by only 0.06% per year, and agricultural productivity increased by 1.52% per year (see Figure 1; USDA-ERS 2011). Hence, virtually all the increase in U.S. farm output during the past 60 years is due to productivity increases and a negligible amount is due to increases in conventional inputs.

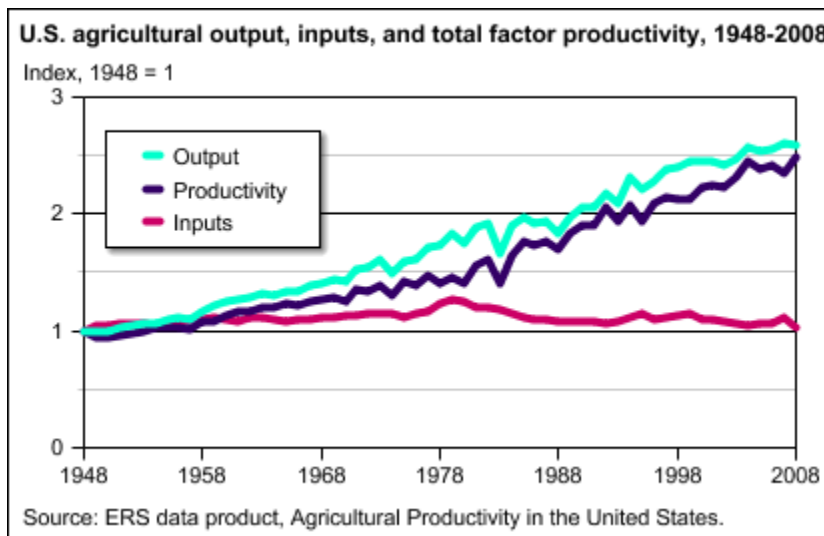


Figure 1. U.S. agricultural output, inputs, and total factor productivity, 1948–2008 (Index, 1948 = 1).

Across the states during a shorter period, 1960–2004, the rate of growth of agricultural output and agricultural productivity differs considerably.

Across the states during a shorter period, 1960–2004, the rate of growth of agricultural output and agricultural productivity differs considerably. Agricultural output has been growing most rapidly in the Pacific Coast states, Idaho, New Mexico, North Dakota, Nebraska, Arkansas, Florida, North Carolina, and Delaware, but much slower output growth has occurred in the Northeast, West Virginia, Tennessee, Wisconsin, and Wyoming (see Figure 2).

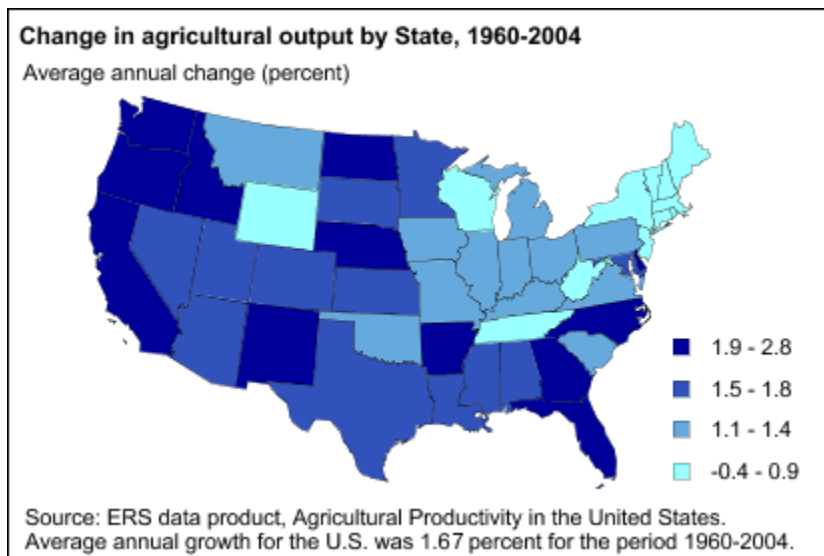


Figure 2. Average percentage change (%) in agricultural output by state, 1960–2004.

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Agricultural productivity has been growing most rapidly in some of the high output-growth states (i.e., Oregon and Idaho), but also rapidly in Louisiana, Mississippi, Illinois, Indiana, Michigan, Ohio, Connecticut, and New Hampshire (Figure 3). Productivity growth has been lagging most in Nevada, Montana, Wyoming, Colorado, Kansas, New Mexico, Oklahoma, Texas, Tennessee, Alabama, Florida, and West Virginia. Empirical analysis of these state-level data has shown that past investments in public agricultural research by the State Agricultural Experiment Stations (SAESs), Veterinary Medicine Colleges (VMCs), the Agricultural Research Service and Economic Research Service (ARS and ERS) of the USDA, and the Cooperative Extension Service are major factors explaining differences in agricultural productivity across states and over time (Alston et al. 2010; Huffman 2010; Huffman and Evenson 2006a,b).

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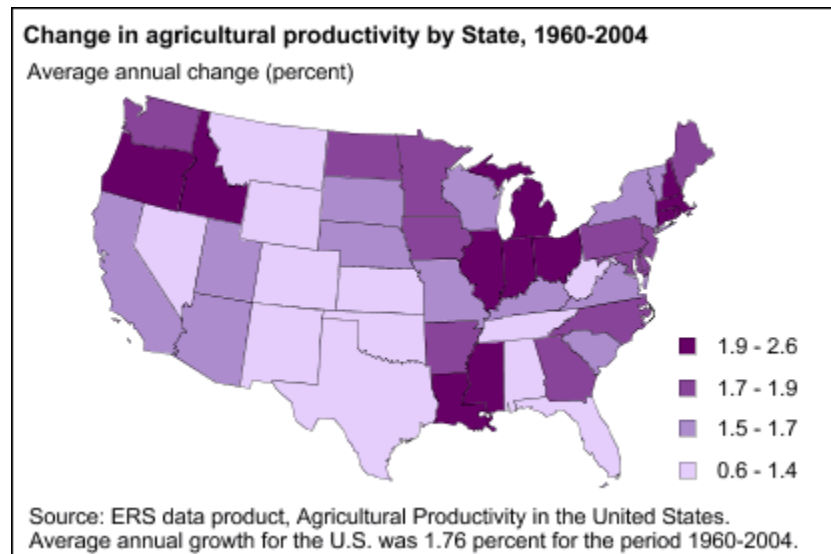


Figure 3. Average percentage change (%) in agricultural productivity by state, 1960–2004.

American agriculture excels relative to agriculture in other developed countries because it has fewer environmental problems; an openness to new technologies, including genetically modified (GM) crops; and larger farms and investments in public and private inputs to raise productivity. The real, constant-dollar volume of farm production inputs in the United States is nearly the same today as a century earlier. In addition, the rapid rise in farm labor productivity of 2.1% per year during 1948–2008 reflects both the labor-saving nature of many new farm technologies and the growing demand for labor in the nonfarm sector to produce other goods and services. Meanwhile, during this period food and fiber outputs have increased by two and one-half times (USDA–ERS 2011). The large number of U.S. farms ensures competition so that each farmer cannot influence market prices. Consequently, benefits of farm productivity have translated into lower food prices. An additional \$4.7 trillion of U.S. farm production inputs would have been required to produce the actual 1948–2008 farm output in the absence of the actual productivity advances during the six decades (Tweeten 2010; expressed in 2008 dollars).

Returns on Investment

The data on U.S. agricultural productivity do not reveal whether or not it was wise to expand agricultural output by investing in nonconventional inputs to lift productivity (T) rather than investing in conventional production inputs (X). The fact that conventional production resources such as land are limited and subject to environmental

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Advances in science and technology take a building-block approach, where later advances build on earlier ones; hence, the R&D needed to develop new technologies for farmers frequently has long gestation periods.

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degradation and climate change points to advantages of increasing output in the future through increased productivity rather than using more conventional inputs. Worldwide, remaining land that might be brought into production is largely in tropical rainforests. Deforestation to obtain additional cropland to produce needed food and feed for the future would have adverse impacts on the environment and biodiversity (Foley et al. 2005).

Producing additional food through the use of nonconventional inputs requires organized R&D and investments in skilled manpower (efforts of scientists, technicians, and laboratory and research assistants) as well as other services (biological materials, laboratories, computers, computer software, greenhouses, offices, and available transportation). In the United States, most of the research in general, basic, and pre-invention sciences occurs in public and private universities and government institutions, whereas applied research is shared among universities, government institutions, and private firms (Huffman and Evenson 2006a). New innovations are further developed and tested by the private sector before they are sold to U.S. farmers and others. Hence, R&D is an expensive activity using resources that have high opportunity costs.

Moreover, advances in science and technology take a building-block approach, where later advances build on earlier ones; hence, the R&D needed to develop new technologies for farmers frequently has long gestation periods. For example, in their research linking investments in public agricultural research to agricultural productivity of states, Huffman and Evenson (2006a,b) have used an empirically based time-lag pattern extending over 35 years (see Figure 4). The initial investment in R&D is made at time 0, and for two years there is no impact on local agricultural productivity; then the impact grows slowly for five years, reaching a peak at year seven. The maximum impact continues for seven more years and then gradually fades away during the next 20 years. This last period with declining weights reflects biological erosion of previous productivity gains and obsolescence of earlier discoveries and innovations, as new discoveries and innovations have occurred. Figure 4 is an approximation for a bundle of public agricultural research undertaken by the USDA and land-grant university system; of course, lags differ for individual discoveries and associated technologies. Related research by Alston and colleagues (2010), however, shows a roughly similar-shaped time lag, but extending over a few more years. Hence, time lags associated with public agricultural research are long, and the benefits from any particular research effort do not last forever. Moreover, long periods of low R&D investment cannot be quickly recovered because of this long time lag.²

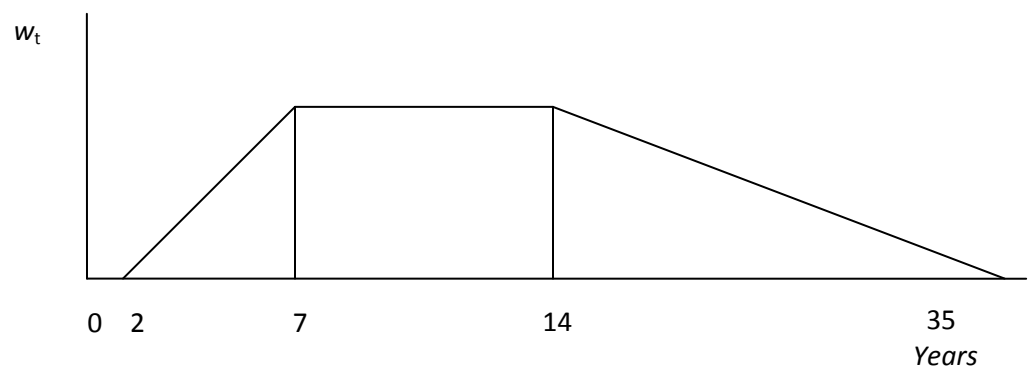


Figure 4. Impacts (w_t) over time of a public agricultural research investment in year 0 (Huffman and Evenson 2006a,b).

² The lag pattern for private agricultural R&D has a similar shape as in Figure 4, but the total length of the lag is at most 20 years, which is largely determined by the length of patents on innovations in developed countries.

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Focusing on the contribution of productivity-oriented agricultural research undertaken by the main U.S. public agricultural research institutions . . . to agricultural productivity in the 48 contiguous states, . . . the marginal real rate of return is approximately 50%.

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Economists compute a rate of return or benefit-cost ratio to weigh the benefits and costs of an investment project, including investing in public agricultural research. The rate of return on an investment can be interpreted as the highest rate of interest that could be paid on a loan to finance that investment while just breaking even. If the costs and benefits in each year are expressed in constant prices, then the computed rate of return is adjusted for inflation, or is a real rate of return. For example, if one invests a bushel of wheat and six months later receives 1.25 bushels of wheat, this is roughly a 50% real rate of return, irrespective of what happens to the price of wheat during this six-month period.

Numerous in-depth studies at the University of Chicago, Yale University, Iowa State University, the University of Minnesota, and elsewhere have carefully calculated the rate of return to investing in public agricultural research. Focusing on the contribution of productivity-oriented agricultural research undertaken by the main U.S. public agricultural research institutions—SAESs, VMCs, ARS, and ERS—to agricultural productivity in the 48 contiguous states, including spillover effects to other states in the same geoclimatic region, during 1970–2004, the marginal real rate of return is approximately 50% (Huffman 2010; Huffman and Evenson 2006a,b). This return compares well with 27 earlier studies on U.S. agriculture showing rates of return of public agricultural research at the three-fourths to one-fourth quartile range of 83% to 28% (Huffman and Evenson 2006a). That is, half of the calculated rates of return fell in a range of 28% to 83%. In a related study examining agricultural productivity of the 48 contiguous states (but using different variables and time period), Alston and colleagues (2010) obtain a benefit-cost ratio of 32 from investing in public agricultural research and extension.³ This latter study implies that the marginal dollar spent on public agricultural research and extension returns 32 dollars to society. Hence, large benefits relative to costs exist for investments in U.S. public agricultural research. Few other public sector investments compare. Thus, in the United States it has been cheaper for society to increase agricultural output by investing in nonconventional inputs (productivity) than by investing in conventional inputs. This picture also holds true for many other countries (Alston et al. 2000).

What else can be said about the benefits from U.S. investments in public agricultural research? First, rapid agricultural productivity increases relative to productivity increases in other sectors of the U.S. economy have translated into falling real prices of food at home. For example, during 1948–2009, the share of U.S. household income spent on food declined from 22.3 to 9.5%, while total consumption of food increased. With Americans spending less than one-tenth of their income on food, the other 90% is available for spending on a wide range of other goods and services, including recreation, housing, transportation, education, and health care. Indeed, the long-term rise of civilization and living standards throughout the world is largely a story about increasing agricultural productivity (Huffman and Orazem 2007).

The demand for food and calories is price and income inelastic (i.e., modestly responsive to price and income changes), and the quantities of food and calories consumed per capita have increased as the real prices of food and calories have fallen and real incomes increased. Consumption of additional food and calories is welfare improving in developing countries but not necessarily for high-income countries such as the United States. When caloric intake exceeds human energy expended on a long-term basis, weight gain occurs. In the United States, the incidence of obesity among adults has

³ Because the latter study aggregates research and extension together and the former study separates them, the two benefit-cost comparisons are not exactly comparable.

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been rising rapidly during the past 35 years, doubling from 18 to 36%—the largest increase in the world.⁴ Obesity leads to a number of health problems, loss of productivity, and increased medical expenditures. Huffman and colleagues (2010) showed that high-income countries that have had a low food-price policy have had higher rates of obesity-related mortality during 1970–2006 than have other high-income countries. Research is ongoing, however, to sort out the effects of prices of different types of foods, income, and other factors on obesity. Rather than suggesting a need to forego the many benefits of agricultural research, the obesity problem begs for new research on diet, food, and health.

Raising agricultural productivity has reduced soil erosion and water pollution, contributing to a better environment.

Human impacts on the landscape are significant, from urban to agriculture. These impacts have resulted in the most prosperous period in human history, but with some challenges, including erosion, water and air quality issues, energy demand, and loss of habitat. New technologies developed for U.S. farmers include a steady stream of innovations such as reduced and no-till farming, insect pest control by genetic modification rather than chemical applications, and GM herbicide-tolerant crops that enable use of environmentally friendly broad-spectrum weed control with increased specificity of chemical compounds. In addition, raising agricultural productivity has reduced soil erosion and water pollution, contributing to a better environment. Higher crop and livestock yields decrease pressures to expand cropping and pasturing on environmentally fragile lands, highly erosive soils, and wildlife areas or to clear forests and drain swamps. Moreover, increasing agricultural productivity and using its products to produce energy directly may be more efficient than producing specific biofuels. For example, Burney, Davis, and Lobell (2010) compared the merits of agricultural research to develop diverse yield-increasing technologies versus biofuel production to reduce greenhouse gases (GHGs). They concluded that agricultural research along these lines was substantially more cost effective than the use of biofuels in reducing GHGs. Agricultural research to raise yields during the 1961–2005 period cost \$4.00 to \$7.50 per ton of atmospheric carbon reduced, which is only a fraction of the cost for biofuels. Crop varieties that yield more grain/beans per acre with a given set of inputs also produce more output per unit of fossil energy input. Hence, although biofuels may have a place in future U.S. energy policy, the merits of each method for controlling GHGs need to be carefully considered, including how new policies and institutions would be expected to affect the attractiveness of alternative strategies.

During the last three decades the growth rate for public agricultural research expenditures has been much slower than the growth rate of agricultural output.

In the United States, broadly defined public agricultural research expenditures grew during two decades leading up to 1980 by an average of 3.2% per year (adjusted for inflation), but no net growth occurred during 1980–1990, and net growth averaged only 0.6% per year during 1990–2009. Hence, during the last three decades the growth rate for public agricultural research expenditures has been much slower than the growth rate of agricultural output (Figure 1). With new intellectual property rights established since 1970, the private sector has, in many instances, assumed a greater role, especially for applied research and technology development (Huffman 2011b; Huffman and Evenson 2006a). The private sector, however, benefits from public agricultural research leading to discoveries in basic and pre-invention sciences, which it then builds on in its R&D programs, suggesting complementariness. There are also tremendous benefits derived from public sector agricultural research through the training of tomorrow's scientists for positions in both the public and private sectors. In some applied areas, however, the private sector has not found it profitable to undertake significant research—e.g., much of U.S. small grain improvement has been left to the public sector. Returns to public

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⁴ Obesity is defined as an individual having a body mass index of 30 or larger. Body mass index equals weight in kilograms divided by height in meters squared.

Given that the biological processes of agriculture are sensitive to local soils, climates, and pest conditions, which are diverse across the United States, local public agricultural-research administrators and their scientists are uniquely positioned to recognize and respond to local research needs and new problems relative to distant federal research administrators.

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agricultural research remain high and suggest the need for large future investments to equalize social returns across public sector investments. Investing in nonconventional inputs for agriculture is a low-cost method of growing farm output, which can be used for food as well as fiber and energy.

How Best to Fund Public Agricultural Research

Public agricultural research is funded by block grants (e.g., federal grants to ARS and ERS, formula funds to SAESs, and state government appropriations to SAESs and VMCs), competitive grants and contracts with mainly federal agencies (e.g., the National Institute of Food and Agriculture, National Institutes of Health, National Science Foundation, Department of Energy, and Department of Defense), and various types of partnerships with the private sector. The actual decision about the program of research to be undertaken with block grant funding is determined at the local level, e.g., by the directors of the various SAESs and their associated university scientists. The actual decision on research to be undertaken by federal competitive grant programs is determined in Washington, D.C., by the funding agency, which in some cases has a users-advisory or science-advisory board to provide broad direction. Given that the biological processes of agriculture are sensitive to local soils, climates, and pest conditions, which are diverse across the United States (e.g., see Huffman and Evenson 2006a), local public agricultural-research administrators and their scientists are uniquely positioned to recognize and respond to local research needs and new problems relative to distant federal research administrators. Public-private partnerships on research involve cooperative efforts. Two decades ago these partnerships looked like a promising source of funding, but various types of conflicts have dampened earlier enthusiasm for this line of funding of agricultural research (Busch et al. 2004).

It is likely that a unit of block grant funding of agricultural research will have a different impact on local agricultural productivity than an equal unit of a federally managed competitive grants program. Moreover, Huffman and Evenson (2006b) showed that each unit of Hatch formula funding of SAES research had a larger impact on local agricultural productivity than a similar unit of federal competitive grant funding. Thus, they showed that at the margin, a reallocation of federal competitive grant funding toward Hatch formula funding would increase state agricultural productivity.

Why is this reallocation not occurring? A misconception exists among managers of federal research funds that they can pick winners, i.e., they can, with high probability, identify research projects that will make major advances in the frontier of science based on a research proposal (Huffman and Just 1994, 2000). The production function for scientific discoveries, however, contains a large amount of uncertainty, including a high probability of no significant advance in knowledge, which undermines externally directed funding. Clearly, there is an issue of how to achieve the correct balance between block and competitive grant funding of public agricultural research, and the evidence is that at the margin adjustments should be toward increasing block grants, as in Hatch Act funding, relative to competitive grant funding.

What does this all mean? The best mechanism design for this task is an implicit incentive-compatible contract between a research administrator and scientists that is repeated many times over time so that it is in the best interests of the administrator and scientists to voluntarily fulfill the terms of the contract. Given this characterization of research and research contracts, it is more efficient for local research administrators than distant federal administrators to contract with university scientists to undertake agricultural research. Additionally, federal block grant funding of SAESs helps

compensate states for research undertaken that benefits other states, e.g., when major breakthroughs occur that are broadly useful.

Why Not Let the Private Sector Undertake Agricultural Research?

Although the private sector invests in large amounts of R&D that lead to innovations that help raise agricultural productivity and improve the quality of life, that sector focuses primarily on areas that have significant profit opportunities, meaning a market with strong intellectual property rights and regulatory systems in place. Organized research to sustain increases in agricultural productivity in the United States and elsewhere is a large and complex enterprise, and the private sector faces weak incentives to undertake research in numerous areas. Following are some examples of why public agricultural research is needed:

Organized research to sustain increases in agricultural productivity in the United States and elsewhere is a large and complex enterprise, and the private sector faces weak incentives to undertake research in numerous areas.

- Farms are too small and certain crops are too minor to bear the cost of R&D to develop most new farm technologies.
- Private agribusiness firms cannot expect to recoup enough benefits to cover the costs of innovations that (1) decrease soil and water erosion and improve air and water quality; (2) analyze impacts of commodity and trade policies; and (3) reveal new information about diet, nutrition, and health as well as about rural and community development.
- Private firms often cannot recoup expenses to undertake research on alternative industrial organization of agricultural and agribusiness companies or alternative regulations of noncompetitive behavior.
- Farmers and consumers need transparent, objective information so that they can make good investment, production, and consumption decisions, but strong intellectual property rights are critical to open information sharing. Intellectual property rights are a key driver of investment in R&D, innovation, and knowledge dissemination in the public and private sectors. Published patent documents offer a vast, accessible source of cutting-edge technological information. Moreover, charging for outlook information, which is a public good, unduly restricts its use.
- Private firms are exploring international markets as a way to increase firm profits, but the United States needs timely and accurate economic intelligence on what is taking place globally. For example, consider agricultural production and policies in China, India, Russia, Ukraine, Brazil, and Argentina, which are major export competitors with the United States. The United States can ill afford to be left behind by unreliable intelligence about agriculture and economic conditions in these countries.
- Private agribusiness firms cannot recoup the benefits from basic or general scientific discoveries that advance the frontiers of knowledge, even though they are worthy social investments. These discoveries are uncertain, frequently occur over a long time span, and produce public goods that are not consumed by others' use. For example, the foundations of the science supporting the GM crop revolution that started in 1996 built on important scientific discoveries spanning a century and a half (Huffman 2011b).
- Private firms have limited interest in on-site training of new scientists for the future. Major doctoral student training is not and will not be undertaken by

private firms. Public and private universities are the source of virtually all the doctoral training in the United States and throughout the world.

Where is Agricultural Productivity Headed?

Evidence is mounting that a new era has begun, with substantially lower rates of productivity and rising real farm commodity prices.

Fuglie (2010), using ERS data, reported an increase in world agricultural productivity growth from 0.49% annually for 1961–1969 to 1.54% for 1990–1999, followed by a decline to 1.34% growth for 2000–2007. Alston, Babcock, and Pardey (2010) stated that the “golden age” of agricultural productivity growth may have ended. They suggested that evidence is mounting that a new era has begun, with substantially lower rates of productivity and rising real farm commodity prices. There are increased pest pressures in many crops, e.g., recent introduction to the United States of Asian soybean rust and the Chinese soybean aphid, spread of the soybean cyst nematode and sudden death syndrome, and some weed adaptation to the herbicide glyphosate. These adverse events in combination with lower rates of growth in the stock of public agricultural research suggest slow agricultural productivity growth during the next two decades (Alston et al. 2010; Huffman 2010).

The private sector . . . has been rapidly increasing its investments in private R&D for agriculture.

Expenditures on U.S. public agricultural productivity-oriented research in constant prices stopped growing in 2004 and declined a little during 2004–2009 (Huffman 2010). The private sector, however, has been rapidly increasing its investments in private R&D for agriculture; e.g., the private seed-chemical industry has invested large amounts in GM crop variety development during 1990–2011 relative to the public sector (Huffman 2011b). This industry is projecting rapid increases in corn and soybean yields during the next 20 years, where the annual rate of increase in bushels per acre per year will be much faster than in the pre-GM period of 1985–1995 (OECD/FAO 2009).

Taken at face value, the problem is that world demand for food will be much larger and limited new land is available.

Sexton and Zilberman (2011) showed sizable increases in crop yields in 25 countries since 1996 due to adopting GM-crop varieties. Moreover, these GM crops are environmentally friendly relative to the chemical pesticides they replaced (NRC 2010). Nelsen and colleagues (2010), however, suggested that the rate of increase in crop yields may slow after 2030, although they projected that crop yields (and production) for corn, wheat, rice, potato, and soybean will be significantly higher in 2050 than in 2010. These, however, are not very precise estimates, being far into the future.

Increased investments in agricultural R&D to raise the stock of agricultural research capital will be needed worldwide.

Taken at face value, the problem is that world demand for food will be much larger and limited new land is available. A major problem in Sub-Saharan Africa is that its geoclimate, culture, weak science capacity, and absence of a regulatory framework are such that Green and GM Revolutions innovations have not been adapted to local farmers’ needs. Moreover, these countries are expected to be adversely affected by future climate change. A step forward would be for Europe and Japan to adopt a more flexible policy on GM organisms. Nevertheless, increased investments in agricultural R&D to raise the stock of agricultural research capital will be needed worldwide.

The Future

United States and world agriculture will likely operate on a new plateau of rising real prices in the future even if the United States invests in public agricultural research at historic rates. Unchanged or declining real investment risks destabilizing major population areas of the world and slowing the future growth of well-being in the United States. The future international competitive position of the United States might be threatened if, for instance, the growth rate of U.S. agricultural productivity falls behind the

corresponding growth rates of productivity in China, Brazil, or India, as some have suggested (Alston et al. 2010).

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Agricultural research is a low-cost source of future agricultural output, but advances in the frontiers of science are difficult and uncertain, translating into long lags. With mean lags of 15 to 20 years, agricultural productivity cannot be easily jump-started after a long period of stagnant investment in public agricultural research. With funding delays, world food prices will rise more rapidly than otherwise projected during the next 40 years.

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Rising real food prices in the United States and worldwide are a sobering thought, especially for consumers in developing regions such as Africa. Consumers in poor regions spend a large proportion of their income on food, as high as 60% or 80% of their income, so food price spikes such as those in 2008 and 2011 constitute major hardship. Still, a meager 0.5% of Africa's agricultural gross domestic product is invested in research to improve farm productivity, and private sector investment there is negligible.

In developed countries, strong intellectual property rights protect discoveries and innovations, and this provides a secure environment for the private sector to develop some of the future technologies that are needed to decrease the demands on conventional inputs, such as farmland and freshwater. Private agricultural research, however, builds on advances in basic and pre-invention science that will only be provided by the public sector. Moreover, there are several applied research areas where the private sector does not invest or underinvests and for which investing is socially beneficial. Larger future investments in public agricultural research in these areas can be expected to provide large social benefits relative to costs and to provide a better future for people of the United States and the world.

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