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Theme Overview: A Future Informed by Agricultural and Social Sciences

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JEL Classifications: O3, O4, Q16, Q18, H54
Keywords: Agriculture Science Policy, Food Security, U.S. Competitiveness, Research Investments

Articles in this theme

Two facts widely acknowledged for some time are increasingly being linked to conclude that the United States has an urgent need to increase its investment in agricultural research: First, the latest population projections from the Food and Agriculture Organization of the United Nations indicate that by the year 2050 the world population will likely increase by 2.4 billion people, reaching 9.7 billion total people and requiring more than a 60% increase in food production from the 2005 level (FAO, 2012; FAO, 2015). Secondly, the major source of growth in agricultural output is due to productivity growth spurred by research innovations, rather than increases in inputs (Heisey, Wang, and Fuglie, 2011; Wang, et al., 2015). Moreover, global food security as a motivation for increased investments in agricultural research is often complemented by the goal to maintain the competitiveness of U.S. agriculture amid uncertainties and challenges due to global climate change.

Diverse groups have recently taken strong positions in support of increased investments in public agricultural research, including producer groups—such as the American Farm Bureau Federation, advocacy groups—such as Supporters of Agricultural Research (SoAR), and international organizations—such as the United Nations Millennium Development Goals.

Perhaps these voices are being heard. The President's FY2017 Budget calls for a total investment of $700 million for the Agriculture and Food Research Initiative (AFRI) research program administered by the National Institute of Food and Agriculture, USDA. AFRI funds are competitive grants which supplement the formula-based Hatch Funds. The $700 million included in the President's budget is the fully authorized level established by Congress in the 2008 Farm Bill, which has never been fully funded in the annual appropriations process. Only one-quarter of the estimated cost of proposals viewed as highly worthy of funding by scientific review panels could, in fact, be funded with the appropriated funds in recent years. For example, the FY2016 funding level was $350 million—half of the fully authorized level but which represented a $25 million increase from FY2015. Recently, both the U.S. House of Representatives and the U.S. Senate Committee on Appropriations approved a $25 million increase for FY2017.

The focus of this *Choices* theme is to underscore the importance of investing in public agricultural research. We do this, first, by providing an overview of trends in U.S. investments in agricultural research and the extension of that research to users. Secondly, since it is impossible to comprehensively describe the contributions made by recent research investments in a *Choices* theme, instead we describe examples of recent agricultural research, one in the livestock area and another in the crops area. (For a more thorough presentation of NIFA's program see USDA, OBPA, 2017.) Huffman's article on U.S. trends shows that after growing rapidly from 1960-1982, growth in public agricultural research investment in the United States then slowed considerably, and even had subperiods of real decline. Huffman also provides measures of social internal rate of return to investments in productivity-oriented public agricultural research and extension, reporting larger rates of return than other recent studies.

The Ballenger, et al. article addresses productivity in the livestock sector for a world population with an increasing demand for meat. Emerging beef genomics research is able to match information on cattle DNA profiles with economically important traits in the marketplace. Cattle producers are currently able to purchase genetic tests for simple traits or relatively comprehensive genomic prediction tools of economically relevant complex traits. The authors review the recent advances in genomic science, interpret those for the *Choices* audience within the context of the supply chain and likely consumer acceptance, and consider the implications of those advances for ranch profitability. It is also worth noting that the research team collaborating on the article is an excellent example of the highly endorsed multidisciplinary approach for translating basic science research into useful applications for stakeholder groups.

The Falck-Zepeda article focuses on the crop sector and the hot-button topic of genetically engineered crops. Approximately 12% of global crop land acres are currently planted to GE crops. While the scientific evidence to date indicates that GE technologies are key to future food security and sustainability, others believe perceived potential threats are not worth the price. The author was a member of the National Academy of Sciences Committee who produced and recently released a much-anticipated report which assessed the existing scientific evidence to offer conclusions and recommendations to help the public and policy makers better understand the issues. His article provides a summary of the key issues addressed in the report, considering economic and social impacts, safety, trade, institutional, regulatory, and policy issues for a world which is increasingly interested in learning more about agricultural production processes.

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New Insights on the Impacts of Public Agricultural Research and Extension

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Keywords: Agricultural Extension, Agricultural Research, Productivity, Returns on Investment in Agricultural Science

In order to feed the growing population of the world, expected to reach 9.6 billion people by 2050—a 29% increase over 2013—without causing immense environmental damage and human hunger, society must increase agricultural productivity. Two ways of achieving this are to invest in public agricultural research and to invest in public extension delivery. The importance of the need for increased investment is widely recognized. For example, in February of 2016, after only a month as the newly elected President of the American Farm Bureau Federation, Zippy Duval supported President Obama's proposed 2017 budget increases for agricultural research (AFBF, 2016) and highlighted the need for increased investment in agricultural research in his April 18, 2016, Congressional testimony (Duvall, 2016). In addition, the importance of investing in agricultural research worldwide is explicitly cited as a target of Goal 2 in the recently released United Nations Sustainability Development Goals (United Nations, 2015).

Developed countries like the United States have been leaders in science-based agricultural productivity increases for most of the 20st century. However, after growing rapidly from 1960-1982, growth in public, productivity-oriented, agricultural research investment in the United States slowed considerably from 1980-1995, and then declined over 1995-1998 by 20% before turning around and showing some growth to 2006, before declining again during the Great Recession. In contrast, rapidly developing countries, such as Brazil and China, are investing heavily in agricultural research, putting future international competitiveness of U.S. agricultural exports at risk (Fuglie and Wang, 2012). Furthermore, consumers worldwide will be worse-off if future investments in public and private agricultural research and extension are not large enough to deliver declining real world food prices in the 21st century.

Given the established importance of investing in agricultural research and extension, those currently engaged in the public agricultural science and agricultural extension policy debates need up-to-date estimates of the expected returns on investment of public funds in both of these activities. Agricultural economists have a long history in developing this "knowledge about knowledge" to provide decision makers with accurate estimates of the returns on investment.

Institutions which Manage Public Research and Extension

In the United States, agricultural research and cooperative extension are separate public programs, each jointly funded primarily by the federal and state governments. Public agricultural research is undertaken primarily by state institutions—state agricultural experiment stations (SAESs) and veterinary medicine colleges/schools. Federal institutions engaged in this activity are the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) and Economic Research Service (ERS). In addition, public agricultural research receives a small amount of funding from the private sector and from non-governmental organizations and pubic extension receives significant funding from county governments.

Although SAESs were established to conduct original research on agriculture, the breadth of the research undertaken has increased over time to include research to improve the rural home and rural life, on agricultural marketing and resource conservation, on forestry and wildlife habitat, and on rural development. Hence, the breadth of the research agenda of scientists of the SAESs has expanded over time, and by the 1970s, research that was undertaken by SAES scientists was actually much broader than what could reasonably be expected to impact agricultural productivity. In addition, the breadth of research undertaken by the USDA has expanded. For example, in 1940-1941, the USDA established four Regional Utilization Laboratories or Centers—Western in Albany, CA; Midwest in Peoria, IL; Southeastern in New Orleans, LA; and Northeastern in Wyndmoor, PA—to undertake research to develop new uses and new and extended markets and outlets for farm commodities and products. Initially, they were independent agencies, but in 1953, the USDA placed these labs under the administration of the Agricultural Research Service (USDA, 2016). In 1972, new federal funding for research on rural development was made available to the State Agricultural Experiment Stations. Hence, the breadth of "agricultural" research undertaken by the public federal agricultural research system has expanded over the past century.

Critical Measurement Issues

In developing measures of returns to investments in public agricultural research and extension delivery, economists address a variety of issues about data and methods. Four critical issues include: separation of those research and extension investments that contribute to agricultural productivity growth from those that do not; accounting for the benefits of investment in one location or farm practice that spill-over to others; identifying the lag effects of an annual investment in research and extension over multiple years; and employing the most appropriate metric for calculating returns to investments. In addition, it is important to think carefully about and identify defensible measures of benefits and costs. In particular, scholars should guard against creating measures of costs and benefits that contain obvious measurement errors.

Agricultural Productivity Investments

As part of the federal-state partnership on funding of public agricultural research, the USDA's intramural research agencies, SAESs, state forestry schools and a few other cooperating institutions agree to provide the USDA's Current Research Information System (CRIS) with research project data. The collected data include a description of each new project by the principal investigator—the commodity or resource that is the target of the research, and the research problem areas (RPAs). RPAs include goals of research to protect crops, livestock, and forests from insects, diseases, and other hazards; and to produce an adequate supply of farm and forest products at decreasing real production costs. With details available in CRIS, it is possible to relatively accurately net out public agricultural research expenditures that clearly do not have a traditional agricultural productivity focus. How much of a difference does it make? In 1970, 70% of the U.S. total expenditures on public agricultural research reported to CRIS were on agricultural productivity-oriented research, and 30% were on all other types. Since then, the share having an agricultural productivity focus has been slowly declining.

The federal, state, and county governments fund public agricultural extension, officially labeled Cooperative Extension. It is primarily adult education for immediate decision making of farmers, households, and communities and youth activities (Wang, 2014). Broadly, the goal has been to provide information for better farm, agribusiness and home decision-making. The youth activities are comprised of "boys" and "girls" clubs, called "4-H" clubs, where members undertake practical projects in agriculture, home economics, and related subjects. In the 1960s, extension added programs in community development and natural resources. Although a gross measure of cooperative extension is possible, it seems most likely that only agriculture and natural resource extension contribute significantly to state agricultural productivity. This requires netting out resources allocated to other types of extension activities, such as home economics, community development, and 4-H. How much of a difference is there between the net and gross measures of cooperative extension? Over 1977-1992, only 55% of the gross measure of extension was accounted for by agricultural and natural resource extension. In addition, in 1977, 30% of the gross extension was allocated to 4-H, but this share declined to 23% in 1992 and seemingly leveled off.

Lags

The investments in public agricultural research and extension have different lengths of time lags for obtaining benefits, being sooner for extension than for research. It is widely accepted that the impact of public agricultural research on state agricultural productivity has a gestation period where the impact is negligible, then blossoms to full marginal impact and then becomes obsolete. We approximate this pattern with a gestation period of two years, during which the impacts and timing weights are zero; the next seven years, during which impacts and timing weights are rising; followed by six years of maturity, during which timing weights are high and constant; and then 20 years, during which impacts and timing weights are declining and fade away to zero by the end of the period. Across this 35-year period, the timing weights sum to one. See Huffman and Evenson (2006). This weighting pattern is known as trapezoidal-shaped timing weight, and they are used to translate real public agricultural research expenditures in a stock of public agricultural research capital for each state. With a lag, the effects of a long-term change in the growth rates of public agricultural research expenditures over time are revealed in public agricultural research capital.

Since extension is largely information for current decision making, 50% of its impacts—or timing weight—occurs within the year undertaken and then the impact and weights decline to zero with obsolescence. (Huffman and Evenson 2006).

Spillovers

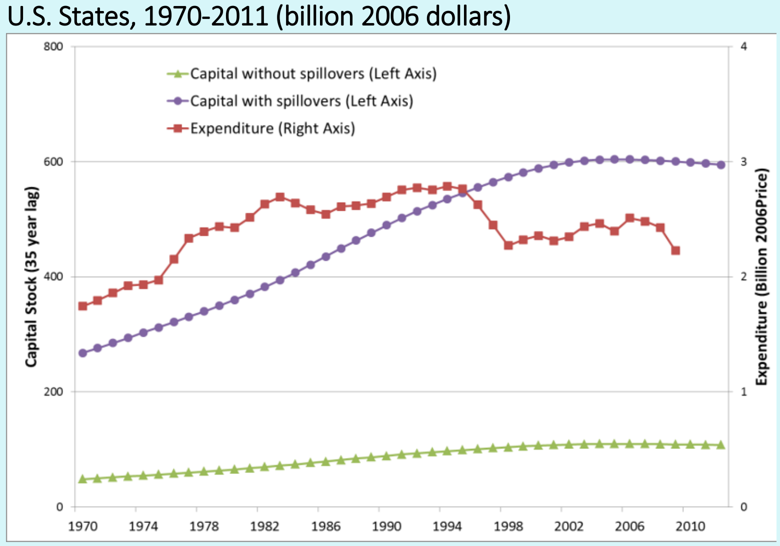
Public agricultural research undertaken in one state produces discoveries that also spill over or are an input into public and private agricultural research efforts in other states and to technologies available to farms and agri-businesses in other areas, producing one type of public good. They can be represented by similarity of agro-ecological zones, output-mix similarities, or geographical proximity. When areas are physically close to one another, it reduces the physical distance that discoveries and information must travel before they can be used by farmers and agribusiness in another area. This reduces one dimension of the costs of information transfers. For example, discoveries made by public agricultural research in Iowa on corn production can easily travel to farmers and agribusinesses in Illinois and southern Minnesota but are less useful in Mississippi and North Carolina. See Huffman and Evenson (2006). Spillover benefits of research undertaken in one state to other states complicates the decision making on funding of public agricultural research in any one state. For example, the spillover benefits might be overlooked. Generally, it is assumed that there are no significant interstate spillovers for public agricultural extension.

Appropriate Bottom-Line Metric

For social cost-benefit analysis where comparison might be made across government funded programs and even internationally, the real—inflation-adjusted—social internal rates of return are better summary statistics than the net present values or cost-benefit ratios estimates. This is because in computing the net present value and the cost-benefit ratio, one must have an estimate of the social opportunity costs of funds—interest or discount rate—in each year of the investment project, and there is no reason to believe that these interest rates are the same in each year of the project (Harberger 1972). In benefit-cost analysis, the size of the ratio is very much affected by the choice of the discount rate used to compute these values.

In developing countries where rates of inflation may be high and variable, it becomes difficult to derive defensible measures of real discount rates. In particular, Evenson (2001) discusses common problems in interpreting benefit-cost ratios for public agricultural research.

Figure 1: Total Public Agricultural, Productivity-Oriented Research Expenditures, Research Capital, without and with Spillovers, 48 U.S. States, 1970-2011 (billion 2006 dollars)

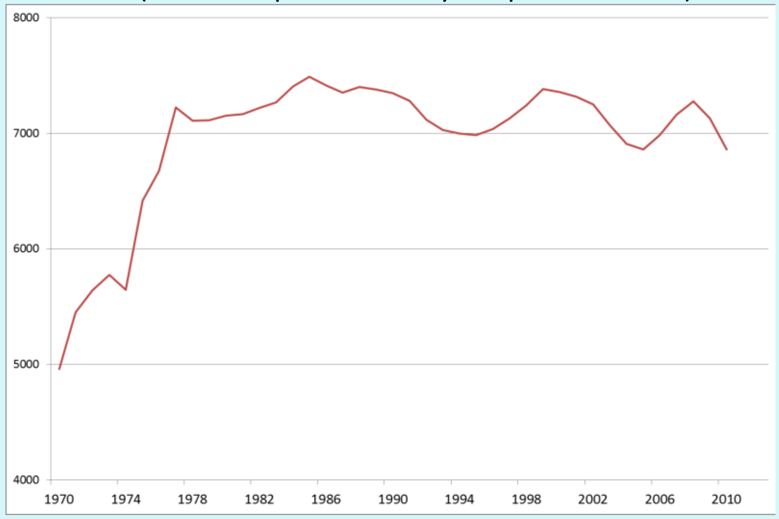


Trends in Public Research and Extension Capital

In Figure 1 the green line shows that the total public, productivity-oriented agricultural research capital across the 48

U.S. states—without spillovers—increased slowly from $47 billion in 1970 to $105 billion in 2006, an average rate of increase of 2.2% per year. The smooth path for research capital (green line) relative to research expenditures (red line) is due to the long lags used to construct the research capital variable. After 2006, the U.S. total public agricultural research capital began to decline slowly, being dragged down by the major break in total public agricultural research expenditures a decade earlier. The U.S. total public agricultural research capital across the 48 states, including each state's spillover component (purple line) is about six times larger than each state's own contribution (green line). Hence, if public agricultural research expenditures in one state is increased by one dollar, on average, it increases the U.S. total public agricultural research expenditures by an additional five dollars. Given the long research lags for public agricultural research capital and the major break in expenditures in public agricultural research that occurred in the mid-90s and continuing, the public agricultural research capital will continue to decline well into the 21st century.

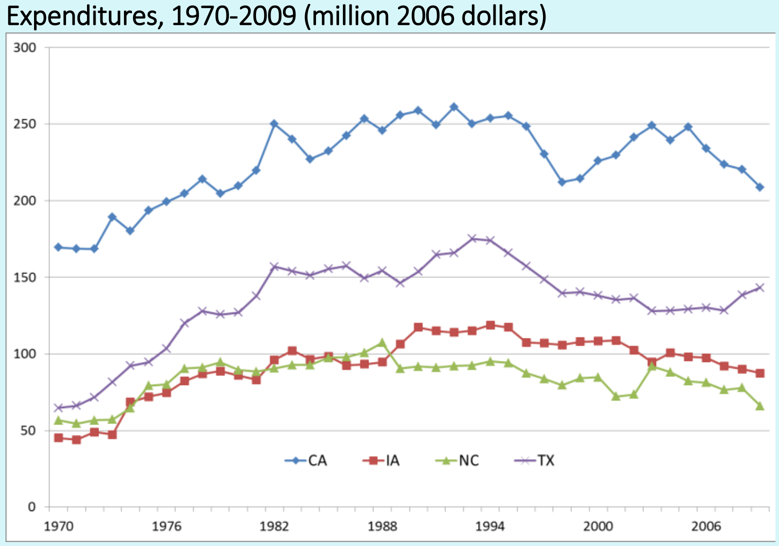
Figure 2: Total Public Agricultural Extension Capital, 48 U.S. State, 1970-2011 (full-time equivalent staff-years per 1000 farms)



The U.S. total public agricultural extension capital per farm grew very rapidly over 1970-1978 at 4.5% per year (Figure 2). However, over the next 33 years there is no net growth, although there have been short periods when the capital was increasing, for example, 1980-1986, 1996-2000, and 2005-2008. However, each of these short periods of growth have been offset by an almost equal decline. With total lag length being only five years for measuring public agricultural extension capital—versus 35 for public agricultural research capital—downturns in agricultural extension can fairly quickly be reversed by increased expenditures on agricultural extension per farm.

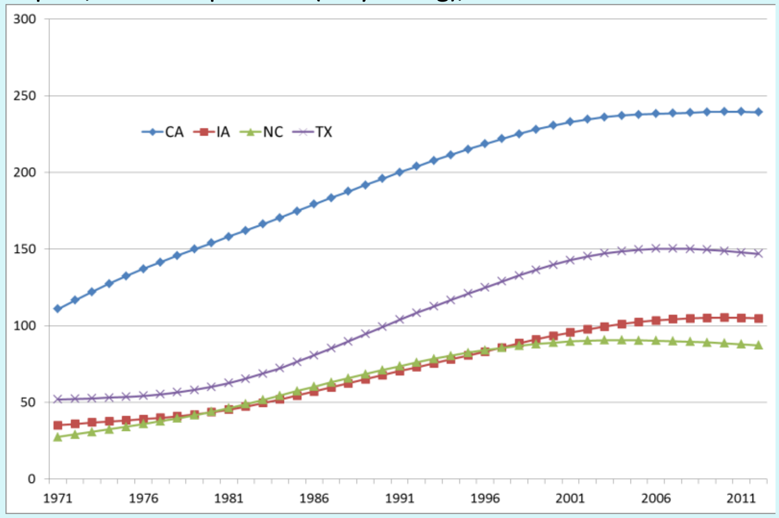
To gain additional perspective on productivity-generating investments in public agricultural research and extension, it is useful to consider four large agricultural states that are in different regions of the country and that differ in products produced: California, Iowa, North Carolina, and Texas. In these states, productivity-oriented public agricultural-research expenditures peaked over the late 1980s and the early to mid-90s (Figure 3a). The peak came earlier in North Carolina (1988), with a later secondary peak in 2005. The peak in California came in 1992, with a later secondary peak in 2005, and the peaks in Texas and Iowa were at the same time as for U.S. total public agricultural research expenditures—1994-1995.

Figure 3a: Real Public Agricultural Research, CA, IA, NC, and TX Expenditures, 1970-2009 (million 2006 dollars)



With long research lags and most of the benefits coming in middle years, Figure 3b, displays a smooth trend for public agricultural research capital—without spillovers—by state, 1970-2011. In addition, research capital peaks later than expenditures, and after peaking, research capital starts to decline slowly. Public agricultural research capital peaks in Iowa, North Carolina and Texas in 2006, as well as for the U.S. total research capital. Public agricultural extension capital per farm, 1970-2011, is displayed in Figure 4 for the four reference states. Since the lag pattern for construction of extension capital is much shorter than for agricultural research, these series are much more irregular over time.

Figure 3b: Real Public Agricultural Research, CA, IA, NC, and TX Capital, without Spillovers (35-year lag), 1970-2011



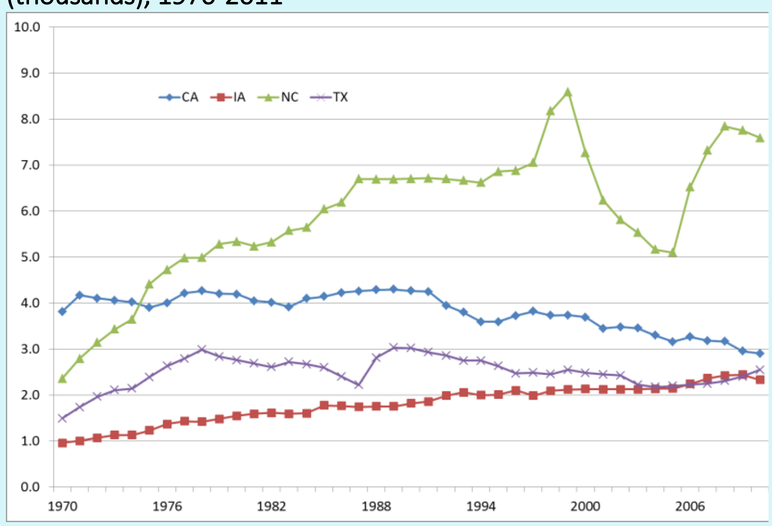
Source: Jin and Huffman (2016).

Rate of Return to Investments in Research and Extension

Using new and updated data and allowing for lags in realizing within state and interstate spillover benefits, Jin and Huffman (2016) provide estimates of the real annual social internal rate of return to investments in productivity-oriented public agricultural research over 1970-2004. They find a rate of 67%. They also report a rate of over 100% for agricultural and natural resource extension. These are large rates of return—for example, relative to a 2-5% return on stocks and bonds—and relative to those reported by other recent studies of a more or less similar nature. Although productivity-oriented public agricultural research is less diverse than total public agricultural research, it remains a heterogeneous mixture of research across a diverse set of agricultural commodities and major input groups and across basic and applied sciences.

Compared to recent studies that have used gross measures of public agricultural research and extension, the estimates of the returns for this study are higher. This is not surprising given that gross measures induce serious measurement errors, which tend to bias estimated benefits downward.

Figure 4: Public Agricultural Extension Capital, CA, IA, NC, and TX: Full-time Equivalent Staff Years Relative to the Number of Farms (thousands), 1970-2011



Source: Jin and Huffman (2016).

A Productive Path Forward

Given the long time lags between costs and benefits for public agricultural research, the decline in the public agricultural research capital starting in the mid-90s will be a drag on U.S. agricultural productivity for more than the first quarter of the 21st century. While the potential losses from that past decline in public research investment cannot be easily recovered, it is uplifting to recognize that more immediate benefits can be obtained from investing in agricultural extension. The importance of investment in agricultural research is widely recognized. Given this unusually large degree of agreement on a public policy issue, perhaps the United States is poised to increase its investment in public agricultural research and extension and thereby ensure a prosperous agricultural sector and continued low food prices for consumers in the future while reducing soil, water, and air pollution.

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30 and Daisy: Where's the Economics in Beef Cattle DNA Testing?

Nicole Ballenger, Chris Bastian, Kristi Cammack, Bridger Feuz, Garry Griffith, and Justin Schaffer

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Keywords: Agricultural Research, Beef Cattle, DNA Tests, Genomic Predictions, Economically Relevant Traits, Adoption Incentives

Have you ever been tempted by the ads for 23 and Me, a DNA testing service so named as each human has 23 chromosome pairs? Or maybe you have already taken the plunge and received your results. Millions have used this test or another to learn their ethnic identities, investigate their health risks, and connect with cousins close and distant (Ossola, 2015). Or maybe you have used a DNA test to identify the breeds that make up your adopted rescue dog, or to verify you have purchased a purebred canine pal. In recent years the uses and potential uses of DNA profiles have exploded. DNA tests are now widely available for deadly serious reasons—like identifying the likely physical traits of the perpetrator of a crime based on a DNA sample found at the crime scene—and for the just-plain curious. While the media has made human DNA testing well known, less may be known or understood about livestock applications.

Suppose you are a cattle rancher, feedlot operator, restaurateur, lover of a fine steak, or just someone wanting to include more beef in family meals—is there a DNA test for beef cattle that can benefit you? Progress has been bumpy, but DNA tests for beef cattle are on the market and beginning to take hold with mainstream cattle producers. Current and prospective tests rely on underlying investments in genomics science and its applications to beef cattle, a research priority for the U.S. Department of Agriculture (USDA) for a number of recent years. Between 2008 and 2014 the USDA awarded $61.5 million for studies of beef or cattle genomics [based on a STAR METRICS search on "(genomics OR genetics) AND (beef OR cattle) NOT dairy (OSTP, 2016)." It is not too soon to contemplate the economic implications and returns to these investments. What information is provided by current DNA tests for cattle; and what might be provided in the future? How widespread will adoption be, and how will adopters use test results? Will those decisions lead to a different quality product; to more affordable beef; to a restructuring of the beef industry? How will the benefits be shared in the multi-stage beef value chain?

First, Some Snippets on SNPs

Most DNA tests—for yourself, your dog, or your cow—now use single-nucleotide polymorphisms (SNPs), pronounced "snips", to identify genetic variations or similarities among individuals, or between an individual and a reference group. What are these SNPs?

The DNA molecule consists of a string of four chemical "bases," adenosine (A), thymidine (T), guanine (G), and cytosine (C). To form the characteristic DNA double helix, hydrogen bonds form between the paired bases, A with T and G with C. A gene is a specific string of these paired bases that provides instructions for making or regulating a particular product, such as a hormone or enzyme. The order of the bases on a string is called a sequence, so the purpose of sequencing a genome—or partial stretch of a genome—is to reveal the linear order of the four bases. Sequencing can then be used to identify places where there is a substitution of one base for another in some percentage of the population being studied. For example, along a particular stretch of the genome researchers might find a G in a particular position 72% of the time and an A 28% of the time. These places, where a commonly located base is replaced with a different base, are the SNPs—also sometimes referred to as point mutations. These SNPs—which may be positioned in a gene or in the DNA sequences in between genes—can serve as markers for diseases and other inherited or genetically influenced traits that can be passed along to offspring. Genomics researchers look for correlations between SNPs and traits of interest, and evaluate the statistical validity and strength of the observed relationships.

Daisy, or any other cow, for that matter, has approximately 22,000 genes arranged on 60 chromosomes—or 30 pairs, one of each pair from each parent. The large number of possible orderings of the four bases that compose these many thousands of genes and DNA sequences in between genes means there are multiple millions of possible SNPs. In fact, the *b. taurus* cattle genome contains about 4 million SNPs (Seidel, 2009). In 2009—the same year *Science* magazine reported the first sequencing of the bovine genome (The Bovine HapMap Consortium, 2009)—the life sciences company Illumina released a commercial SNP evaluation system for cattle that made it possible to rapidly analyze up to 50,000 SNPs spaced throughout the genome. This “50K chip,” which was developed in collaboration with USDA’s Agricultural Research Service (ARS), Pfizer Animal Genetics, University of Missouri, the National Association of Livestock and Artificial Insemination Cooperatives in France (UNCEIA), and the French National Institute for Agricultural Research (INRA), provided a substantial boost to research aimed at matching SNP profiles with economically important cattle traits (Matukumalli et al., 2009). As an indicator of the boost received, the number of USDA-supported project progress reports that include the terms “SNPs” and “beef cattle” rose from 14 in 2000 to 90 in 2012 (USDA-NIFA, 2016b). Recently, the process of identifying associations between individual SNPs and traits of interest has been replaced by a process known as genomic selection, which looks at the relationships between all 50K or more SNPs imputed up through statistical inference to the full sequence (Meuwissen, Hayes, and Goddard, 2016).

Beef Genomics Research Matches SNP Profiles with Economically Important Traits

Animal scientists conducting SNP association studies face a number of significant challenges despite huge advances in genomic prediction technology. First, there must be a sufficient number of “phenotypes” to match with SNP profiles. Phenotypes are actual cattle that exhibit objective measurements of the economically important traits of interest. Many hundreds or thousands of animals may be needed for statistically significant correlation results. Some breed associations, such as the American Angus Association, have long collected extensive amounts of information on offspring of sires, which makes SNP correlation studies more feasible for Angus cattle than for other less established or less-studied breeds. Public research entities, such as USDA’s Meat Animal Research Center (MARC), establish study populations for other breeds and mixed breeds; MARC validates study results by comparing them with results of SNP studies conducted at other research centers with other large cattle reference populations, for example in Australia and Canada (Pollak, 2012).

Second, even for breeds with large amounts of phenotypic data available for SNP matching studies, data may not have been collected for all genetic traits or trait indicators of interest. For example, a cattle breed association might have recorded information on birth, weaning, and yearling weight, but not on feed conversion efficiency, meat tenderness, nutritional quality, or a newly emerging disease. Feed conversion efficiency, for example, is an especially costly trait to study in cattle and therefore not routinely measured by breed associations.

Third, traits of interest in the cattle sector have varying degrees of "heritability," which refers to the proportion of phenotypic variation due to genetic variation. Most traits are influenced by a combination of genetics and environment, just as in humans. For example, certain indicators of reproductive performance in cattle, such as scrotal circumference, have high heritability and others, such as calving intervals, have low heritability (Field, 2007). The degree of heritability affects the degree of confidence with which scientists can link SNPs with inherited performance traits. Furthermore, no matter how strong the match between an animal's SNP profile and its propensity to pass along desired traits to its offspring, it still "takes two to tango." The other parent's genomic profile may be just as important in determining the performance merit of their calves.

Complex Traits are Trickier to Match with SNPs than Simple Ones

Genomics research for beef cattle has tried to match SNPs with both simple and complex traits. Simple traits are those controlled by a single pair of genes. Simple cattle traits include qualitative—or observable—traits such as coat color, pigmentation, horned or not horned, double muscling, and a variety of undesirable genetic defects and diseases that can plague cattle producers, such as dwarfism, hairlessness, marble bone disease, mulefoot, and palate-pastern syndrome (Field, 2007).

Some simple traits have significant economic benefits or costs. Returns to genetic technology designed to select for hornless animals were found to be quite high in Australia where a dominant breed is the naturally horned Brahman (Griffith and Burrow, 2015). The simple trait "color" may be economically valuable for some cattle producers. The Certified Angus Beef program, for example, requires the animal be at least 51% black to meet the phenotype requirement, and Angus steers and heifers may bring higher prices than non-Angus contemporaries (AgriCultured, 2016). Double muscling—the result of a SNP in the myostatin gene that controls muscle development—can lead, according to some, to a leaner and healthier choice for consumers, but also to larger calves and more calving difficulties (Alford et al., 2009; Schaffer, 2015).

However, most economically relevant traits in cattle are complex traits, which means they are controlled by multiple pairs of genes, and are therefore more difficult to match with SNPs than are simple traits. Complex traits are typically quantitative—or measurable—traits that may be grouped into those that affect productivity, such as various dimensions of reproductive performance and weight gain; production costs, such as feed conversion efficiency; or product quality, such as meat tenderness and marbling. Genomic scientists search for and have found SNP associations for quite a few of these elusive economically relevant, complex traits, but with varying degrees of statistical validity. As just two examples among a great many, one study of feed conversion efficiency found strong SNP associations on seven different chromosomes (Abo-Ismail et al., 2014); and a study of calving ease found 13 closely associated SNPs on just one chromosome (Bongiorni et al., 2012). However, complex traits typically have low heritability, such that parental DNA alone is insufficient for predicting phenotypes because other factors, such as temporary or permanent environmental influences, genomic imprinting, and genetic recombination, come into play.

What DNA Tests for Beef Cattle are on the Market Now?

There is no DNA test called *30 and Daisy*, although we think there should be. However, as shown in table 1, there are a number of genomic tools for beef cattle available on the market now. Some earlier tests were removed from the market due to weak predictive performance, and the genomic testing industry is still experiencing considerable flux—as evidenced by oft-changing company names and products. The currently available tests typically offer results for simple traits, as well as parentage verification. Only two companies—Neogen and Zoetis (formerly Pfizer)—offer comprehensive genomic prediction tools at prices ranging from less than $10 to test for parentage and some simple traits, to $79 to obtain information on a panel of economically relevant complex traits.

Table 1:

Company	Tests and traits included	Cost	Source
AgriGenomics	Coat color and 12 genetic defects	$18-$25	http://agrigenomics-inc.com/species.html
Biogenetic Services	Parentage, coat color, BSE resistance, two genetic defects, meat quality		http://biogeneticservices.com/index.htm
Eureka Genomics	Parentage	$5-$15	http://www.eurekagenomics.com/ws/products/bovine.html
Genetic Visions	Coat color, milk yield, protein yield, tenderness, five genetic defects,	$25-$40	http://www.geneticvisions.net/
Quantum Genetix (formerly GenServe Labs)	**Q-Sort** tests for carcass traits and feed efficiency. **Q-Link** tests for parentage. Coat color, horned/polled, leptin, protein yield, 9 genetic defects	$10-$45	http://genetix.quantumgenetix.com/home
Neogen – Agrigenomic Solutions	**Igenity Comprehensive** tests for performance traits (residual feed intake, average daily gain, weaning weight), carcass traits (tenderness, marbling, ribeye area, fat thickness, carcass weight), maternal traits (birth weight, calving ease direct, calving ease maternal, stayability, heifer pregnancy, docility, milk), simple traits (myostatin, horned/polled, viral diarrhea, coat color), and 15 genetic defects **SeekSire** parentage testing	$25-$50	http://www.neogen.com/Genomics/
Veterinary Genetics Lab (UC Davis)	Coat color, parentage, polled/horned, protein yield, milk trait, four genetic defects	$10-$65	https://www.vgl.ucdavis.edu/services/cattle.php
Repro Tech	Fertility	$40	http://www.reprotec.us
Zoetis Animal Genetics (formerly Pfizer)	**HD 50K for Angus and Red Angus** tests for coat color, polled/horned, tenderness, 8 genetic defects; calving ease direct, calving ease maternal, birth weight, weaning weight, average daily gain, dry matter intake, net feed intake, mature weight, milking ability, carcass weight, back fat thickness, ribeye area, and marbling score **SireTrace** parentage testing	$9-$79	https://www.zoetisus.com/animal-genetics/beef/index.aspx

Source: Van Eenennaam (2010) and author updates.

Toward Mapping the Economics

The cattle industry has been selecting and breeding for genetics for over 200 years (Olmstead and Rhode, 2008). Genomic tools, if effective, “merely” speed up the process by providing information about inherited traits that are not readily observed or cost-effectively measured, and about the expected genetic merit of breeding bulls and cows that are too young to have proven performance records. What each cattle producer or buyer has to decide is if the current cost of buying a genomic tool is worth the benefit down the road in the form of more valuable or less costly-to-raise offspring. This calculation depends on both how valid the test is—how accurately it can predict the desired traits in the offspring—and how much value there is in enhancing those traits in the offspring.

Who are these cattle producers and buyers who might want to consider benefits v. costs of DNA testing? Beef production involves multiple stages along a vertical value chain: a seed stock sector, cow-calf operations, stockers and feedlots, processors, retailers, and final consumers (Field, 2007). In relation to poultry, hogs, and dairy, beef production involves longer biological cycles spread across a larger geographic area. Additionally, ownership of the animals in the value chain can change multiple times across the industry segments (Mintert, Shcroeder, Brester, and Feuz, 1997). Consequently, there is less vertical coordination and control in the beef industry than in other livestock sectors. In a practical sense, this has implications for how benefits of using genomic tools are likely to be captured or shared in the beef supply chain. For example, a typical Wyoming cow-calf operator does not retain ownership of her animals once they’re loaded on a truck and bound for feedlots, usually in neighboring states. Could she recoup the costs of having invested in DNA tests? Norwood and Lusk (2008) and Van Eenennaam and Drake (2012) make the case that although investments in beef genomic tools may generate value for each sector of the beef industry, they will be less profitable than in poultry, hogs, and dairy because of the relative lack of vertical control in the beef sector.

Expected Progeny Difference versus Genomics Information

Expected Progeny Difference (EPD) – An estimate of expected difference in the performance of future progeny for a particular characteristic or trait based on data from ancestors of a particular animal, the sire or dam in question, and the records of their progeny. For example, records on weaning weights are used to calculate the expected progeny difference for weaning weights if a particular bull is used. This is often expressed as a plus or minus in pounds. A bull with a weaning weight EPD of +31, means that calves from this bull are expected to be 31 pounds heavier at weaning compared to calves from an average sire. Often, EPDs are reported with a projection of accuracy. The closer to one, the more accurate the EPD is in predicting impact of using a particular sire for a particular trait. The EPD is based on past records of animals and does not use genetic information from DNA.

Genomics Information – Genomics uses DNA marker tests to identify specific regions of chromosomes where genes are located that affect a particular trait. Many traits have multiple genes that affect them. A DNA test is performed to see if a particular animal has favorable combinations of alleles affecting the trait of interest. This information must be combined with information on the percentage of genetic variation explained by the test, accuracy of the test, data related to differences in performance, and heritability of the trait to predict a difference for a trait from a particular parent. Thus, genomics alone is not a predictor of performance, but improvement in animal and herd performance can be enhanced when combined with EPDs as genetic marker information can allow for early prediction of genetic merit for an animal.

What is actually known about current and prospective adoption and economic returns to DNA tests for cattle is still very limited. The seed stock sector does appear to be one portion of the beef industry that is widely adopting genomic tools, though there is not a reliable estimate of the extent. Vestal et al. (2013) find it is not uncommon for bull sale catalog entries to provide genomic test results alongside other standard information about the expected genetic merit of sires—called Expected Progeny Difference (EPD). (See Box) Interestingly, these researchers found that adding DNA test information did not result in higher bull prices in their study, but they anticipate prices will respond as buyers become better at interpreting genomic test results.

As buyers of DNA-tested bulls, cow-calf ranch operators may be already benefiting from genomic information; however, there's little evidence about use of genomic tools on the ranch itself. At a recent meeting with some Wyoming stock growers, most said they were "not very knowledgeable" about today's genomic tools, most had never used them, and most identified testing costs as a barrier to adoption. Nonetheless, most participants said they are interested in potentially using DNA tests to better predict several economically relevant traits, especially reproductive performance, calving ease, and feed conversion efficiency. They were also interested in how DNA testing might help them decide which heifers—cows that have not yet had calves—to retain for breeding. These responses make good sense because cow-calf operators make more money if they lose fewer calves at birth, can increase the number of calves weaned per cow in the herd, expand the productive life of a cow or bull, or reach a desired weaning weight with less feed. These are traits over which the rancher may have some control, and even more so with the use of accurate, affordable DNA tests (Mitchell et al., 2009).

Beyond the ranch gate, the benefits of genomic tools are the subject of a small number of studies. We can imagine DNA tests might enhance the potential for a feedlot operator to contract with cow-calf operators who can verify their animals will achieve slaughter weight more quickly in the feedlot environment, or exhibit more valuable carcass traits, or be less likely to be susceptible to feedlot illnesses such as Bovine Respiratory Disease. DeVuyst et al. (2011) assessed the benefits of Neogen's Igenity panel test, which, as table 1 shows, provides scores for a variety of growth and carcass traits of interest to feedlot operators, including average daily gain (ADG), marbling, rib-eye area, tenderness, fat thickness, and USDA Yield grade. They found statistically significant but somewhat low correlations between the Igenity scores and the observed values of these traits in the study animals. In addition, they found that of the panels analyzed only the marbling score contributed a net positive financial return. Thompson et al. (2014) evaluated the value to feedlot operators of using comprehensive tests with information on seven economically relevant traits to manage and sort cattle already in the feedlot. The authors found that marbling and ADG panel scores resulted in higher feed lot profits, but the cost of testing was larger than the associated returns.

Further downstream, genomic tools may increase interest by restaurateurs and retail chains in contracting directly with commercial beef producers. Such arrangements do happen now, as with *Nolan Ryan All Natural Beef*, but they are not the industry norm. DNA tests may hasten the trend toward such arrangements by making it easier for sellers to guarantee a particular quality of end product or for buyers to find it. Some companies, no doubt, will see potential value in controlling genomics from breeding to the dinner plate.

In addition to needing to understand the incentives for adoption by each industry segment, we will need to also assess how benefits of adoption are likely to be shared along the supply chain. As an example, Weaber and Lusk (2010) attempted this when they examined how using genomic tools to select breeding stock for meat tenderness could play out in changes in market prices and quantities throughout chain. They considered both consumer demand for tenderness and genetic testing costs, and concluded substantial economic benefits would be shared among industry participants over 20 years.

Could Consumer Perceptions "Snip" Away at Potential Benefits?

Borrowing a page from the history of genetic engineering of plants, consumer perceptions of genomic technologies for beef cattle also need to be studied sooner rather than later. If we had to predict, we would guess that interested consumers will "like" the use of genomic tools to select for some traits—for example, calving ease—but might "dislike" it for others. Although genomic prediction tools are not intended for the creation of "frankencows," some consumers will fear that's next. Ellen Goddard of the University of Alberta and colleagues in Europe are currently undertaking surveys of consumer perceptions in Canada and Europe (Goddard, 2013), but so far as we know no such efforts are underway in the United States.

USDA puts priority on "animal breeding, genetics, and genomics" research because "dramatic improvements in yields of animal protein are crucial in meeting the ever-increasing food needs in the United States and around the world" (USDA-NIFA, 2016a). According to experts, advances in genomics have the potential to bring about significant gains in efficiency of beef production (Goddard, 2012). Genomic science continues to advance and SNP studies for beef cattle to multiply. Meanwhile only a handful of economic analyses have assessed the profitability of DNA testing of cattle. To understand implications for food security, we need a good grasp of the status of genomic predictions of productivity and cost-reducing traits, the ability of commercial tests to deliver this information accurately, incentives for adoption in the commercial cow-calf sector, and the price and quantity effects of incorporating selection for such traits into the genetic stock.

Economic analyses could help USDA prioritize investments in genomic research on economically relevant traits: where's the biggest expected bang for the buck? In Australia, economists have used a full beef industry model to assess returns—and their distribution across industry segments—to past genetic improvements (Farquharson et al., 2003; Zhao et al., 2000), and various R&D impact tools to calculate benefit-cost ratios for new genetic technologies developed by the Cooperative Research Center for Beef Genetic Technologies (Griffith and Burrow, 2015). Working in tandem with genomics experts, who can tell us more about the potential timeline and likelihood of development of genomic advancements, economists could evaluate which genomic advancements offer the most promise in terms of both net economic benefits and successful development. Economic analyses could also inform regulatory questions that may emerge down the road, such as the benefits of public or third-party validation services for beef genomic tools (Van Eenennaam et al., 2007). If you buy that *30 and Daisy* test kit, you'll want to know what you're getting and whether it's worth the cost.

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Experiences and Prospects of Genetically Engineered Crops

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The debate about genetically engineered (GE) crops has become increasingly polarized in the United States, Europe, and some developing countries. The debate polarization has not been resolved in and by the complex and seemingly divergent literature that examines the impacts of the actual and potential adoption and commercialization of GE crops in industrialized and non-industrialized countries. To better understand the rich literature accumulated over the past twenty years, the National Academies of Sciences, Medicine and Engineering (NAS) established a committee of experts to compile existing questions and issues from the public, collect and assess existing evidence and draw a set of findings, conclusions and recommendations to help the public and policy makers understand better the complex landscape.

The NAS Committee objective was to review the accumulated literature to better assess the purported positive and negative impacts of GE crops, as well as the institutional framework in which these technologies have been released. The analysis also included assessing the potential role that emerging genetically engineered technologies will play on future crop improvement efforts and their impact on long term goals such as food security. This article summarizes the U.S. National Academies Report. In addition, the article provides the current article author's personal clarification notes about the content of the NAS Report. Furthermore, while the NAS Report has a global focus, this article directs attention to the most important issues discussed in policy dialogues in the United States, while highlighting relevant issues and aspects from other countries.

The Experiences

In 2015 there were an estimated 180 million hectares—or 445 million acres—planted to GE crops in 23 countries, representing roughly 12% of the world's total cropland. Almost all GE crops planted worldwide are corn, soybean, cotton, or canola engineered to tolerate specific herbicides or resist certain insect species. Other cultivated crops have been engineered for virus resistance and other traits, namely papaya, beans, squash, potatoes, and apples.

Environmental Safety

The insect-resistance trait introduced into GE crops is based on genes taken from *Bacillus thuringiensis* (Bt), a soil-borne bacteria that produces proteins that are toxic to specific insects including a variety of crop-damaging lepidopteran insects. Evidence collected in the NAS Report indicates that Bt cotton and maize in the United States, China, and India have been effective in reducing the pressures posed by targeted insect pests. While the research is still limited, Pakistan can be added to the list of countries contemplated in the NAS report.

The NAS report documented evidence that in the United States and other countries, applications of synthetic pesticides have decreased as a result of farmers adopting Bt maize and cotton, thus providing an environmental benefit. There is also evidence that in some instances, farmers who did not adopt may have benefitted from overall reductions in local pest populations. However, the failure to pursue resistance management strategies by farmers in some countries created the conditions for Bt resistance to emerge more quickly than the expected long term emergence of resistance, thus reducing the effectiveness of the technology over time. Although, Bt has proven effective against its target pest, it does not control other types of insects that can damage the crop, thus requiring farmers to pursue additional management strategies to deal with secondary pests as their populations built up over time. The NAS report indicates that this has been an agronomic problem only in a few instances.

The herbicide-tolerant trait allows farmers to spray specific herbicides such as glyphosate to control weeds without damaging the crop itself. Application of glyphosate and other herbicides allowed the possibility of substituting other weed control chemicals. This outcome can be construed as an environmental benefit. Consider that a number of authors in the literature have indicated that the substitution of other herbicides for glyphosate, caused a reduction in the overall toxicity load as glyphosate has a lower toxicity than the herbicides used before.

The NAS report describes evidence over the last twenty years showing increases in the use of herbicide tolerant traits in crops and in the adoption of improved soil management practices (specifically, zero or minimum tillage cultivation) that require retention of crop residues from previous crops. The NAS report indicates that establishing causal relationships between the two is difficult. As expected for an herbicide tolerant GE crop, the NAS Report found evidence in the United States and other countries of declines in the level of other herbicides used in agricultural production during the first years of adoption, and an increase in the herbicide for which tolerance was incorporated as a trait.

However, evidence in the NAS report also indicates that the decline in herbicide use has leveled off in many instances. In the case where glyphosate is used extensively, weeds susceptible to the herbicide have been replaced by those less susceptible to the herbicide thus requiring higher herbicide application rates and/or an increase in the number of applications of herbicide. Furthermore, there is evidence for the United States and other countries that some weeds have evolved resistance to glyphosate over time. This gradual process introduced more pressures for increased herbicide use. To address these issues the NAS Report identified the need for better herbicide management strategies to help delay the emergence of herbicide resistance and thus extend the technology's life cycle.

Human and Animal Safety

The track record of GE crops regarding human and animal health safety has been widely studied. National authorities test GE crops using three approaches including animal testing, nutritional composition analysis, and allergenicity assessments. Although the NAS report found that there is a need to improve the design and analysis of animal testing protocols, findings confirm reasonable evidence of no harm to animals in the multiple studies evaluated. In the case of nutritional composition, in some instances there were statistically significant differences between a GE crop and conventional counterparts, although these differences were within the observed range of variation that naturally occurs within each crop.

Due to the expressed concern over the potential impact of GE crops consumption on a number of health issues, the NAS report examined the level of incidence in selected countries. The NAS report describes its examination of long term epidemiological datasets from the United States, Canada, United Kingdom, and Western Europe for evidence of health issues including cancer, obesity, gastrointestinal tract illnesses, kidney disease, and allergenicity. The NAS report found no pattern of difference after the introduction of a GE crop during the 1990s in the countries examined.

Agronomic and Crop Improvement

The NAS report also reviewed evidence on the extent to which GE crops contribute to reducing damage by insects, yield improvement, and other associated productivity gains. When viewed from a broad perspective, the NAS Committee indicates that there is no evidence to suggest an increase in average rate of yield growth in historical trend data from the United States and other countries for cotton, maize, or soybeans that might be attributable to the adoption of GE crops.

As discussed in the NAS report and in the literature, many other factors beyond GE crop adoption help explain long-term yield growth. These include genetic gains achieved through conventional plant breeding, improvements in plant breeding tools and techniques, better crop and resource management practices on the farm, changes in the use-efficiency of inputs such as fertilizers and agrochemicals, access to infrastructure such as roads and irrigation, and changes in the incentives provided by market signals and public policy, among other issues.

Some first generation GE traits introduced in crops to date are engineered to embody resistance to pests, weeds, and disease. This means that the intended effects are to protect the crop from damage in a more cost-effective way than conventional methods such as insecticide applications and not to increase the crop's potential yield per se. In the case of herbicide tolerance, GE traits allow substituting weeding by hand or machine for chemical control and to introduce additional time flexibility in terms of when chemical weeding can be done. In effect, this means that replacing conventional control methods with GE crops should not be a reason to expect yield increases per se when compared to its conventional counterpart.

Economic and Social Impacts

Evidence reviewed in the NAS Report indicated that in the case of maize, soybeans, and cotton embodied with insect-resistance and/or herbicide-tolerance traits, the financial and economic outcomes have been generally favorable for adopting farmers. Outcomes range from reductions in production costs to increases in crop revenues to increases in time available to pursue other activities, such as off-farm employment and income. Each GE technology comes with a wide range of costs and benefits that vary between the large mechanized farms in industrialized countries to smallholder farms in developing countries and within locations and over time.

Despite concerns that GE seeds would be a costly burden to farmers—especially farmers who plant saved seeds from previous harvest—the NAS Report found limited evidence to support this contention, while evidence of farm-level analyses supports the notion that higher seed costs are offset in many cases by revenue increases from reductions in crop damage and cost savings from lower input use, resulting in positive economic outcomes.

The NAS Report indicates that future adoption patterns are likely to be determined by how farmers assess these costs and benefits in the context of their own situations, including the affordability of GE seeds and complementary inputs, their access to markets and price information, and their ability to manage the GE crops effectively. The NAS report recommended more research into the adoption, diffusion and impact of GE crops on smallholder farmers including those access limitations such as seed cost, access to productive inputs and institutional constraints such as credit and extension services.

In the case of herbicide tolerance, the NAS report found evidence that the trait provides management flexibility and reduced time required to manage the crop. In some instances in the United States, some evidence shows that additional time has been invested by family farm members in securing off-farm employment. These findings help explain the high adoption rates of herbicide tolerant GE crops in spite of no yield differences and small to no direct economic benefits in existing assessments of such crops in the United States. In all instances, the evidence presented in the NAS report shows that the utility of a specific GE crop trait is directly connected to the farm and household context and the performance and cost of GE crop seeds.

International Trade

In the trade of agricultural commodities between countries, GE crops have introduced what is commonly referred to as "regulatory asynchronies" into international trade flows. Consider the case of countries that have invested significantly in developing and regulating GE crops such as the United States, Canada, Argentina, and Brazil. In all of these countries, GE crops—particularly maize and soybean—have been approved under domestic biosafety regulatory systems as safe for consumption for food and feed. Commodities produced using approved GE crops in a country may be exported to countries where biosafety regulatory approvals have been issued. This allows the importing country to reject shipments containing unapproved GE crops based on biosafety laws and regulations. Furthermore, some countries have introduced unilateral moratoriums and bans on GE crops trade and even cultivation. These types of actions can disrupt international trade and put undue pressure on countries that pursue different decision-making approaches or are at different stages in developing their domestic regulatory systems and capabilities. As the international trade in GE commodities increases, greater cooperation between and among countries will be needed to address these challenges.

As more GE crops are introduced and internationally traded, in many cases with multiple traits combinations, the expectation is that trade disruptions related to GE crops will increase. If this situation is not resolved through international cooperation, this may become a very expensive development, with implications of significant cost increases for exporting and importing countries.

The disruptions resulting from regulatory delay issues may be compounded by variations in how different countries approach the issue of GE labeling. The NAS report review of the evidence shows that both mandatory and voluntary labeling approaches have their own set of advantages and disadvantages. A major disadvantage of the mandatory approach is that it tends to impose a cost on those consumers that do not require or are not willing to pay significantly higher food prices. In particular, certain countries have mandated labeling for all GE crops that express a GE trait beyond some threshold or tolerance level. That level may have an impact on the cost of the labeling scheme: more restrictive tolerance levels—that is, those close to zero—tend to be more expensive and more difficult to implement.

Voluntary labeling approaches address this issue by allowing consumers to pay a price premium that may be associated with non-GE crops that may be valued by some consumers segments. Voluntary approaches require coordinated action and compliance among producers which adds complexity, such as increased knowledge and information flows, to the value chain. The increased complexity may thus become a disincentive to provide desired information about a food required by some consumers. There are other considerations as well, such as consumers' right to know about the nature of their food, as well as ethical, religious, and philosophical dimensions of food—all of which warrant discussion at the community and national levels.

Contributions to Food Security

The NAS Report indicates that that there is little evidence to suggest that GM crop adoption has improved long-term food security in a broad sense. This is not particularly surprising as decades of accumulated evidence have demonstrated that a single suite of technologies alone are insufficient to end hunger and malnutrition at a global scale. This does not imply that technology cannot play a significant role in addressing multiple and increasingly complex challenges compounded by climate change to help address sustainable intensification. From the standpoint of valuable GE crops, it is important for this technology to remain as a valuable tool that may contribute to addressing current and future productivity limitations.

Prospects for GE crops

The NAS Report indicates that newer GE tools and technologies, such as gene editing, will likely lead to a wide range of benefits including direct yield increases, improvements in crop protection against pests and diseases, greater crop tolerance to abiotic stresses such as drought and extreme temperatures, improved efficiency from photosynthesis, or any combination of these and other traits. But the realization of these gains will be highly dependent on the world's ability to address policy and institutional constraints that may otherwise limit innovation.

The U. S. Innovation System

The NAS Report discussed evidence that investments in public research for crop improvement, GE crops and other areas of R&D has declined over time. The implication is that there may be underinvestment in crops of a public interest, which may not provide significant market returns to developers. The NAS report recommends reversing this trend. Investments in crops of a public nature may be facilitated by an intellectual property (IP) regime that supports innovation.

The NAS report shows that there is disagreement in the literature on the impacts of intellectual property tools, such as patents. These may support or deter innovation and knowledge sharing. In some situations patents, including utility patents, may be used as a strategic tool to block competition. This may be the case for larger firms which may have the needed resources to secure patents and thus exclude smaller firms and plant breeders who may not have sufficient resources to cover licensing fees and challenge patents that may not have been properly granted in the first place.

In contrast, the NAS report also highlights a small set of studies presenting evidence from developing countries, where patenting and other IP systems may have helped promote private sector investments in plant improvement practices. Due to the conflicting literature, the NAS report recommends more research into understanding the way that IP may facilitate innovation in crop improvement while granting access to improved germplasm and seeds especially by small farmers in developing countries.

Access to seeds usually is supported by a competitive seed sector. The NAS report presents evidence that in the United States there are some indicators showing increased concentration in the seed market. However, there is not enough clarity as to the effect of market structure and conduct on seed prices. The NAS report recommends that more research is needed to understand the relationship between market concentration, conduct, and performance, and how pricing mechanisms work especially with the advent of multiple traits being stacked into a single crop.

The U. S. Regulatory Landscape

Unlike conventional crops, GE crops have to comply with biosafety regulations designed to evaluate their potential impact on human and animal health and to the environment prior to commercial release. Competent regulatory authorities determine whether a specific GE crop technology is safe for release to the public. In the United States, the competent authorities are the EPA, USDA-APHIS, and the FDA. In other countries, national biosafety committees and regulatory agencies play a similar role of examining GE crops' safety.

The evidence consulted in the NAS Report shows that all methods used to improve crops can introduce changes that have the potential of becoming a safety issue. A critical recommendation in the NAS Report is that regulatory systems overseeing GE crops should not focus their attention on a specific GE crop based on how it was researched and developed, rather the focus should be on whether the trait in the product is novel. This is the approach taken by Canada in its biosafety regulatory system. Furthermore, the NAS Report recommends that any new crop variety that introduces a novel trait undergo biosafety evaluations.

Even though the biosafety system in the United States is technically product based, in practice USDA and the Environmental Protection Agency (EPA) determine what products to regulate in part based upon the process by which the crop is developed. This approach is becoming outdated and with the new emerging technologies, the distinction between a GE and conventionally bred crop will diminish dramatically to the point of being indistinguishable.

In addition to pursuing trait novelty as a regulatory trigger, the NAS report also recommends a tiered integrated approach that incorporates novelty and a focus on assessing intended and unintended effects, but also includes considerations such as potential hazard and exposure. Potential hazard identifies the impact and a level in which a negative outcome may occur, while potential exposure identifies how much a consumer will indeed be in contact with a potential hazard. It is therefore worthwhile exploring different risk based regulatory assessment models to further improve regulatory systems in the United States and in other countries especially as the new plant breeding GE techniques blur the distinction of GE crops with conventional breeding approaches.

As the policy and regulatory environment has been affected by polarization in the public opinion debate, policy makers and regulators are well advised to significantly increase their public communication efforts using strategic approaches that may help address public concerns. Researchers and product developers are also well advised to pursue communication strategies that build trust based on openness and transparency to ensure effective science-based communication. This approach is unlikely to resolve the existing polarization but will help address consumers' and the general public's issues and concerns.

Institutional Issues Paramount

An overall conclusion that we can draw from the NAS report is that the institutional context in which GE crops have been and will be researched, developed, deployed, and adopted is paramount to their contribution to improving society's welfare and sustainability. The multiple institutional issues affecting GE crops were, indeed, a major item identified during the course of the public consultations and in the literature review for the NAS Report. Institutional issues such as intellectual property regimes, seed systems, market coordination, and integration, access to credit and financial services, access to productive inputs and to knowledge and information about technology use and markets, ability to access infrastructure may not be binding constraints in the United States and other industrialized countries, but can be real constraints in developing countries especially for smallholder farmers.

GE crop developers—especially those in the public sector—are advised not only to focus on the technical performance of such technologies, but also focus on the overall development strategies which may have an impact on the proper deployment and eventual success of such technologies. As described in the NAS Report, in some developing countries, much of observed success of GE crops adoption can be directly tied to a receptive and often coordinated value chain and institutional context. Not taking the institutional context into account may increase the likelihood of failure for a technology that has the potential of addressing many productivity issues, even those not directly addressable by existing technologies. Paraphrasing Gouse (2008) it is prudent for society to avoid the situation with GE crops where we may have "technological triumphs and institutional failures."

Research and Policy Lessons for the Future

Consumers, Non-governmental Organizations (NGO), and special interest groups have taken more proactive roles in driving the food system discourse since 1996, when GE crops were first released. The original business model focused on farmers and in improving farmer productivity through the release of performance improving technologies that had been so successful, will need to change dramatically. Certainly, science-based approaches and evidence will play a major role in shaping the future landscape for crop improvement efforts, whether for GE or any other type of crops, but also consumer concerns and social, ethical, and in some cases religious concerns are now part of the debate. The expectation is that the research and development, policy, and regulatory communities will be able to recognize this challenge and to proactively develop new business models to ensure the proper deployment of existing and future technologies that may be valuable to ensure foods security and other short and longer terms goals.

One of the important overall lessons we can draw from the NAS Report is the need to recognize that there are many gaps, uncertainties and methodological issues related to existing assessments of GE crops in the literature. This is not a surprising state of affairs in the technology evaluation literature. Researchers, policy makers, and other public stakeholders are encouraged to embrace diversity and uncertainty in order to pursue multi-pronged approaches to the evaluation of GE crops and any other technology. This is a prudent approach that can help temper the conclusions from any evaluation effort. It is also prudent to focus on the strength of the evidence but it is equally necessary to address all public concerns and issues and to carefully evaluate the evidence.

This approach may be able to build up trust through enhanced transparency and proper consideration of biases and conflicts of interest as they may even affect the choice of evaluation methods. The current debate underscores the importance to acknowledge that the framing of many issues raised about GE crops have very little to do with science and are more drawn from ethics, religion, philosophy, and personal perceptions and biases. Finding robust and consistent methodologies to address the latter continues to be a challenge.

The NAS Report compiles existing evidence that support the finding that there are no known substantial concerns about environmental and human/animal health aspects of existing GE crops. Newer GE crops may bring additional challenges but also opportunities in terms of their ability to address productivity constraints while contributing to ensuring food security. To realize this potential it is necessary to enhance innovation, regulatory approaches and evaluation processes. Above all there is a need to improve the ability to properly frame the technology in its societal context that has become more complex over time. Only in this contextual framework will GE crops continue to be a powerful tool with much potential to improve society's welfare.

For More Information

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