Modernizing Agriculture: A Continuing Process

Wallace E. Huffman

Iowa State University, whuffman@iastate.edu

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Agriculture in the United States has undergone dramatic technological and social-economic structural change during the past century. Theodore W. Schultz was the first to emphasize the role of science-based technological change as a key force for causing agriculture to undergo a transition from traditional to modernizing conditions. It is now well established that institutionalized research, not research undertaken by farmers themselves, is the key factor for producing innovations or knowledge leading to new technologies and advances in agricultural productivity under modernization. In the United States, it has taken many decades to develop the legal, political, scientific, and economic structure for the agricultural R&D system.

As technological advances occur, a type of economic disequilibrium is created. For the modernization of agriculture to progress, it is not sufficient simply to have the creation of knowledge. Advances in science must lead to new technologies adapted to farmers' needs and then commercialized; information must be supplied about the potential of new technologies; and farmers must adopt them. Furthermore, technical advances in agriculture create a demand for further advances in science to refine the scientific principles underlying them and to resolve new problems that emerge. In agriculture, the performance of most technologies is sensitive to local climate, soils, and economic factors, so the potential for local adaptation is great and the impact of new technologies varies widely across locations on a
given farm and across farms. This makes information dissemination and adoption decisions difficult because a simple decision rule is seldom appropriate. More generally, it is costly for farmers to acquire information, evaluate the available technologies, and adopt only the new ones that are expected to increase their profit. Farmers need to be tied into a receptive and productive agricultural research system.

The objective of this essay is to outline some of the key dimensions of the modernization of U.S. agriculture and to suggest that schooling in the country could learn important lessons from the organization and development of agriculture in the United States.

BEGINNING THE MODERNIZING PROCESS

How did the modernizing process for U.S. agriculture get started? Relatively parallel developments of institutions for higher education, research, and extension to serve agriculture broadly were needed. It is now easy to forget that in the mid-1800s the necessary institutions, a useful body of scientific knowledge, and human resources in trained scientists and educated farmers were missing; a large investment was necessary before institutionalized agricultural research would have technological successes with farmers.

Much of the invention and technological improvement in U.S. agriculture before 1840, and to a lesser extent up to 1900, came about from the activities of private individuals. Although equipped with little formal research training, they faced practical agricultural production problems or sought improved methods of production. These individuals were innovative farmers, blacksmiths, and estate owners; accordingly, a large share of the technical advances from this informal system was realized in the form of mechanical innovations rather than biological advances.²

Agricultural societies provided early support to teaching and research institutions. Keen interest arose within these societies about the latest techniques, fertilizers, and implements. The climate they generated—a mixture of innovation, competition, and dissemination of results—formed an integral part of the
“clientele” relationship that exists between farmers, the extension service, and agricultural research institutions. The early societies demonstrated the usefulness of research and education in improving agriculture, while also providing political interest-group support for the use of public funds for research and education in agriculture.3

Federal legislation was necessary to establish central pieces of the U.S. public agricultural research, education, and extension system. A legislative act established the United States Department of Agriculture (USDA) in 1862; the Morrill Act of 1862 established land-grant colleges; the Hatch Act of 1887 provided for state agricultural experiment station support; and the Smith-Lever Act of 1914 provided for agricultural extension support.4 These legislative acts and the institutions developed and supported by them were major innovations in the development of agriculture. Yet they were not simply imagined into existence; by the time each of these major pieces of legislation was passed, considerable institutional development and experience with earlier institutions had been realized.5 The U.S. Patent Office was a precursor to the establishment of the USDA, and early state colleges of agriculture were a precursor to land-grant colleges. Agricultural experiment stations first developed in Europe, especially in Germany in the mid-1800s, and served as an interesting model because they sought methods of applying laboratory science, especially chemistry, to agriculture. Both in Europe and as developed in the United States, these institutions were not part of or affiliated with a university, however, and the distribution of their results to farmers was not a major focus of their activity. Farmers’ institutes, traveling agricultural-college short courses, and USDA field demonstration activities were turn-of-the-century precursors to the federal-state cooperative extension.

Between 1862 and 1887, several forces were pulling for the development of organized agricultural research in the United States. First, the newly established land-grant colleges created a demand for research to enhance the information content of their teaching programs in agriculture and home economics. Second, research methods were weak, hindering knowledge accumulation and scientific credibility. For example, in 1862
virtually no information existed on the chemical composition of agricultural products, soils, fertilizers, and agricultural waste; standard laboratory procedures did not exist for most chemical analyses. This made for slow advances in the chemical-content knowledge base and led to early credibility problems for the chemistry profession. Third, between 1802 and 1898 the U.S. government made six major land acquisitions that completed the shape and area of the continental United States, and through successive policy choices worked to move federally owned lands into private land holdings. During the nineteenth century the frontier advanced westward across the country, bringing much new land into agriculture production. But developing new lands raised many new technical problems, which in turn heightened demand for agricultural science and technology. Fourth, before 1815 the transportation of agricultural commodities on dirt or mud roads and rivers meant high freight rates and relatively little interregional competition. But as canals and railroads were added to the U.S. transportation system during the remainder of the nineteenth century, a dramatic drop occurred in interregional transport costs. Farmers on the relatively poor soils of the east coast states confronted immense competition from the new farmers on the good soils of the Midwestern states.

And whether facing new challenges of turning the prairie into cropland or encountering new competitive pressures on established farms, farmers frequently turned to their local state government for assistance—including state support for public land-grant colleges, agricultural experiment stations, and agricultural extension. Between 1875 and 1887, fourteen states established agricultural experiment stations. The Connecticut State Agricultural Experiment Station, established initially at Wesleyan University in 1875, was the first successful one. The passage of the Hatch Act in 1887 was the most important legislative step in institutionalizing public agricultural research in the United States. The legislation was much debated between political interest groups of the north and south and between “states rights advocates” and “federal control proponents.” To gain passage of the legislation, control of state agricultural experiment stations was given to the states, leav-
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ing the USDA with the relatively minor role of aiding and assisting them. Each qualified state was to receive an equal federal appropriation of $15,000 per year to support a station; and, in contrast to the German model, the stations were to be established under the direction of a state land-grant college or university. The stations were mandated by the legislation to acquire and spread practical information connected to agriculture and to conduct original research. After passage of the Hatch Act, state agricultural experiment stations were quickly established in all states.

This brief history shows that both the performance and the funding of agricultural research in the United States has been shared between private and public interests. From 1890 to 1990, real public agricultural research expenditures of the USDA and the state agriculture experiment station (SAES) system grew at an average annual rate of 4.2 percent; private sector real agricultural research expenditures grew at a rate of 4.8 percent during the same period (see figure 1). The relative size

Figure 1. Expenditures on SAES, USDA, and U.S. Private Agricultural Research, fiscal years 1888–1990 (constant 1984 dollars)

Note: For 1888–1955, private research expenditures are available only at ten-year intervals, so the solid line connects the points for those years. This also affects the graph of total expenditures.

of the USDA and SAES research system has switched twice over this period, in 1918 and 1948; but since 1948 the SAES system has been a considerably larger research enterprise than the USDA. Private agricultural research expenditures in the United States are generally accepted to be larger than public expenditures since about 1950.\textsuperscript{10}

With the land-grant colleges and state agricultural experiment stations in place, the various states and the USDA searched for a mechanism to educate farmers and rural people and to disseminate farm and home information to them. Part of the struggle arose from the very different information needs and social structures in the northwest and south. In the south, the USDA had early successes by seeking cooperation with state and local organizations, working with and through local farmers, and using local demonstration fields to illustrate selective and better management practices; but working through the land-grant colleges proved less than successful. By contrast, in the north and west, extension work was generally associated with applied research of the land-grant colleges, especially farm management research. Information was supplied through college and traveling short courses and distribution of publications to farm households.\textsuperscript{11}

The third significant legislative innovation came in 1914, when passage of the Smith-Lever Act smoothed over differences between the north and south in organizational philosophy for extension work. The Smith-Lever Act provided for cooperative extension between the land-grant colleges and the USDA in each state. The Cooperative Extension Service aided in diffusing useful and practical information on subjects related to agriculture and home economics and to encourage its application. The agricultural colleges were to establish extension departments to give instruction and practical demonstrations. Each state was eligible for a federal appropriation of $10,000 per year plus additional federal funds to be allocated among states on a formula based on a state's share of the rural population. Of course, the mechanism for allocating federal funds to Cooperative Extension has changed over time,\textsuperscript{12} and the revenue for Cooperative Extension has come to consist of federal, state, and local sources.
DEVELOPING A SYSTEM OF AGRICULTURAL SCIENCES AND TRAINING SCIENTISTS

Both a system of applied agricultural sciences and methods for training agricultural scientists were needed before new technologies could be developed that would support farmers' research needs and the modernization of agriculture. The early training of agricultural scientists could advance only after a new science system for agriculture was created and in place. To establish this system, research methods were borrowed from the general sciences (e.g., chemistry, botany, physics); others were developed to meet the special circumstances associated with agriculture and home economics in land-grant colleges. The creation of the new system occurred largely between 1862 and 1920. The years from 1900 to 1920 are now seen as a period when the public agricultural research system was under great stress because few important advances in science were being made. Yet it was during this era that a system of agricultural sciences came of age. The change came about in part by agricultural research developing ties to the core sciences, but more importantly by investing in "pretechnology science," intermediate between core science and applied agricultural science. Furthermore, much applied research became multidisciplinary.

The R&D system for agriculture did not develop as a linear organization of science and technology. In a linear organization, advances in science lead directly, albeit with some lag, to advances in technology, without any feedback in the opposite direction. In contrast, in agriculture, science and technology developed bi-directionally: advances in science led to advances in technology, and advances in technology led to advances in science. It might be thought that this sort of exchange would run counter to the differing cultures of scientists and technologists. Yet because of the agricultural roots of most agricultural scientists, the scientists and farmers saw the importance of feedback between them.

With the periodic strengthening of intellectual property rights (e.g., in the 1930s, 1970s, and 1980s), the boundary between publicly- and privately-funded research has shifted. During the late nineteenth century a large share of research for U.S.
agriculture was in the public sector. Over time this has shifted, so that now more than two-thirds of all U.S. agricultural research is conducted in the private sector. Interestingly, the private sector continues to find large investments in general or core scientific research unprofitable, as well as applied research in areas where commercially saleable products and information are not easily obtained (e.g., natural resource and environmental research, open pollinated crops, food safety and human nutrition, agricultural and rural policy). This means that public-sector research has become more concentrated over time in core and pretechnology sciences.

Low cost and efficient exchange of knowledge among scientists (and innovators) is important for refereeing priority claims to innovations but also for the accumulation of verified hypotheses that constitutes scientific knowledge in a field. Scientific communication systems were first developed to facilitate horizontal exchange among researchers in the core or basic sciences. To facilitate this exchange, scientists developed specialized language and measurement procedures to achieve exactness and credibility. In most sciences, this is the language of statistics, experimental design, and exact measurement. The journal papers, reference citations, specialized language, and elements of style are chiefly designed to allow scientists working on similar problems to disclose findings quickly and accurately to one another.

The science exchange system that originated in the core sciences has been modified and used in pretechnology science and to some extent in technological inventions. Scientific papers, with their specialized language usually associated with a discipline and with standards set by scientists themselves, have been a very important vehicle for horizontal exchanges. Downstream and upstream exchanges of knowledge are more difficult because some of the language and style that facilitates horizontal exchange hinders other types of exchange.

During the nineteenth century, public agricultural research was limited by a weak scientific knowledge base and the small number of individuals that were trained or being trained to do scientific research. Most of the early agricultural research was "art" rather than "science." The early U.S. agricultural scien-
tists were largely sent to Germany for training, especially in agricultural chemistry. During the eighteenth century, completing a Ph.D. degree in the German model was an indication that an individual had successfully mastered a body of knowledge and the skills needed to advance the state of knowledge in the sciences. Gradually the training of U.S. agricultural scientists evolved into a program requiring advanced course work in the sciences, training in research methods, and supervised experience in conducting and reporting research.\textsuperscript{17}

**PERFORMANCE AND CHANGE IN U.S. AGRICULTURE**

During the past century, U.S. agriculture has faced two persistent long-term challenges requiring structural change: technological change and rising real wage rates in the nonfarm sector. (There are, of course, other forces of a short-term and less dramatic nature that have also affected agriculture.\textsuperscript{18}) The U.S. agricultural sector has undergone major economic and social change as it has adjusted to these forces and become more thoroughly integrated into the U.S. and world economies.

**Forces for Change**

Although regional markets for agricultural products were relatively well integrated by the turn of the century, the extent of integration of farm and nonfarm input markets has been debated.\textsuperscript{19} It seems that before 1933, farm and nonfarm input markets were poorly integrated, but by the 1970s they had become well integrated.

The expected compensation from nonfarm employment represents an opportunity cost to farm labor when the two labor markets are integrated. Table 1 provides information on the real wage rate for production workers in manufacturing. These jobs have generally been accessible to workers in agriculture, and wage data for production workers in manufacturing are available at regular intervals going back one hundred years. The data in table 1 show that real manufacturing wage rates rose by a factor of 5 (or an average of 1.6 percent per year) from 1890 to 1990; real compensation rose faster, by a factor of 7.6 (or an average of 2.1 percent per year). These are large...
Table 1: Historical Data on U.S. average wage rates of production workers in manufacturing and agriculture, and legal minimum wage, 1890–1989.

<table>
<thead>
<tr>
<th>Year</th>
<th>Manufacturing Wage</th>
<th>Farm Wage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. weekly hours paid$^a$</td>
<td>Avg. hourly wage ($/hr.)</td>
</tr>
<tr>
<td>1890</td>
<td>54.0$^b$</td>
<td>0.16</td>
</tr>
<tr>
<td>1900</td>
<td>53.2$^b$</td>
<td>0.18</td>
</tr>
<tr>
<td>1910</td>
<td>51.0</td>
<td>0.21</td>
</tr>
<tr>
<td>1920</td>
<td>47.4</td>
<td>0.55</td>
</tr>
<tr>
<td>1925</td>
<td>44.5</td>
<td>0.54</td>
</tr>
<tr>
<td>1930</td>
<td>42.1</td>
<td>0.55</td>
</tr>
<tr>
<td>1935</td>
<td>36.6</td>
<td>0.54</td>
</tr>
<tr>
<td>1940</td>
<td>38.1</td>
<td>0.66</td>
</tr>
<tr>
<td>1945</td>
<td>43.5</td>
<td>1.02</td>
</tr>
<tr>
<td>1950</td>
<td>40.5</td>
<td>1.44</td>
</tr>
<tr>
<td>1955</td>
<td>40.7</td>
<td>1.86</td>
</tr>
<tr>
<td>1960</td>
<td>39.7</td>
<td>2.26</td>
</tr>
<tr>
<td>1965</td>
<td>41.2</td>
<td>2.61</td>
</tr>
<tr>
<td>1970</td>
<td>39.8</td>
<td>3.36</td>
</tr>
<tr>
<td>1975</td>
<td>39.4</td>
<td>4.81</td>
</tr>
<tr>
<td>1980</td>
<td>39.7</td>
<td>7.27</td>
</tr>
<tr>
<td>1985</td>
<td>40.5</td>
<td>9.54</td>
</tr>
<tr>
<td>1989</td>
<td>41.0</td>
<td>10.47</td>
</tr>
</tbody>
</table>


$^a$ Before 1940, hours paid for and hours worked were almost the same. After 1940, employers started paid leave programs. In 1989, paid-for leave time is roughly 10 percent of paid-for work time (Department of Labor, 1989.)

$^b$ Estimates from related series.

$^c$ Deflated by the price index in the last column.


$^e$ Dollars per day 1890–1950; dollars per hour, 1950–1989.

$^f$ Consumer price index (Bureau of Labor Statistics) up to 1960; after 1960, implicit price deflator for personal consumption expenditures (Bureau of Economic Analysis). The BEA’s series rise less rapidly during the late 1970s mainly because it uses comparable rental rates on owner-occupied housing rather than interest rates.
increases, and represent a powerful force for pulling labor out of agriculture over time—and possibly for causing labor-saving technical change in agriculture.\textsuperscript{20}

Technical change is difficult to summarize adequately. Innovations in science and technology make possible improvements in products, production processes, intermediate inputs, biological and other materials, and management and information systems. In agriculture, for an innovation to be successfully adopted by farmers they must expect that it will increase their profit. Yet only a small share of all potential agriculture technologies will actually be adopted by farmers. The primary impact of new technology on the economy thus occurs at the technology diffusion stage, where new products and processes are spread across the potential market. Hence, measuring the impact of new technologies must focus on identifying and measuring how the economy changes as new technologies are introduced and used.

Three types of indicators of technical change exist: observed successful innovations, the number of inventions, and productivity change. Technological successes like hybrid corn provide concrete, but highly selective, examples of how a new technology is developed and adopted. Although the first scientifically successful “hybrids” were obtained in corn in 1907 by public-sector researchers, thirteen more years of research and experimentation were required before the first commercially successful hybrid corn variety was developed (for Connecticut). Another decade of research and development was required before commercially successful hybrid corn varieties were developed and available to farmers in the Corn Belt.\textsuperscript{21} Starting in the 1930s, hybrid corn varieties rapidly replaced open-pollinated corn varieties in the Corn Belt, and then spread to other corn growing states. As research and development continues—that is, once successful varieties are replaced by a superior new one—new research makes past discoveries obsolete. Hence, in hybrid corn and most agricultural technologies, the technology used by farmers keeps changing as new discoveries and improvements occur.

U.S. farmers produce for national and international markets with a profit objective. Because a large share of the new technologies are inferior to the current technology used by a farmer
and because profitability depends on local geoclimatic and economic conditions, making good adoption decisions is difficult; skills obtained through schooling seem unambiguously to contribute to successful choices. Successful adoption of new technologies (varieties, biotechnology, information systems) has been shown to increase the profits of early adopters. In a competitive market, early adopters of superior technologies will have reduced real costs of agricultural production; lower-cost producers will increase their output and take a larger share of the market. In contrast, late adopters will lose because they will face lower output prices compared to the old technology state. Nonadopters will face lower profits and may be forced to exit the industry. In agriculture, new technologies have frequently changed interregional comparative advantage, sometimes giving an advantage to farms of a particular size.

The number of inventions (e.g., patents or new varieties) can provide a useful summary of the pace of change at the technology frontier. For example, consider cultivators and plows. Few patents in this class were granted before 1830; in the 1830s and 1840s, there were 115; 226 between 1850–1859; 1,683 between 1860–1869; 1,308 between 1870–1879; 1,152 between 1880–1889; and then, in the decades following, new patents tapered off. Yet if patent counts provide rough indexes of the pace of invention, they are not very useful for assessing the economic impact of technical change.

Productivity analysis is an economist’s attempt to approximate the “ultimate” impact of technical change on useful output without trying to identify “intermediate” successful technologies or count innovations. To accomplish this, economists have developed measures of total factor productivity (TFP) that express aggregate output per unit of aggregate input (rather than per unit of one input, say labor or land). The growth of aggregate output that cannot be explained by aggregate input (under the control of producers) is defined as TFP. Careful aggregation of outputs and inputs to account for quality and compositional changes are important to obtain an informative measure of TFP and one that will be a good proxy for technical change.
Over the past hundred years, U.S. agriculture has a remarkable record of total factor productivity growth: the average annual rate of TFP growth has been about 1.6 percent per annum. For the past fifty years, the growth rate of total factor productivity for U.S. agriculture has been even higher, about 1.9 percent (see figure 2).

Although TFP statistics for other sectors of the U.S. economy do not extend back a century, Jorgenson and Gollop have constructed measures for nine sectors including agriculture for the post–World War II period. They show that the average annual TFP growth in the agricultural sector over the 1947–1985 period exceeded the corresponding rate for the U.S. private nonfarm economy by more than 3.5 times. It was more than double the rate of TFP growth for the manufacturing sector. Furthermore, among their nine sectors that cover the private economy, the average annual TFP growth rates for the agricultural sector over the period 1947–1985 were significantly larger than for all other sectors, except for the communications sector. Moreover, they conclude that productivity growth in U.S. agriculture is different from the rest of the economy. For agriculture, productivity growth accounted for 82 percent of the growth of output, while for the rest of economy, productivity accounted for only 13 percent of the growth.

The relatively rapid TFP growth of U.S. agriculture during the past century can be interpreted as relentless technological change or modernization. These TFP increases of 1.6 to 1.9 percent per year accumulate into a very large long-term impact. Given measures of TFP and R&D activities, economists have chosen to use econometric techniques to relate TFP to past investments in R&D, among other things, and to skip the intermediate stages of invention, adoption, and diffusion of technologies. Although there are potential problems with correctly identifying causal relationships, the evidence has yielded a generally impressive story.

One example uses TFP data for a crop, livestock, and aggregate agricultural sector in forty-two U.S. states from 1950 to 1982. Such an approach shows that investments in public and private agricultural research, public agricultural extension, and farmers’ school are a major part of the explanation for varia-
tion cross-sectionally and for overtime in TFP for agriculture. Their public and private research variables are derived as weighted expenditures over the past thirty-three years. The extensive lag length takes account of the fact that expenditures on research do not immediately produce innovations; there is selection and further testing before commercialization, and once a useful technology is marketed it is not immediately adopted by producers. Furthermore, some advances in knowledge are an input into later research and may be useful over many years.33

Structural Change

U.S. agriculture has undergone major structural change over the past century. In 1890, U.S. farms numbered 4.5 million; and the number grew steadily to 6.4 million in 1910. Little change then occurred until the Great Depression pushed the number to 6.8 million in 1935. Farm numbers decreased most rapidly from 1950 to 1969, going from 5.4 to 2.7 million. Since 1970 there has been a slow decline in farm numbers. In 1990, there were only 1.9 million U.S. farms, about 30 percent of the number at its peak in 1935.

Aggregate U.S. farm output was about 5.5 times larger in 1990 than in 1890 (an annual average growth rate of about 1.7 percent). The rate of growth of aggregate output was significantly faster after 1935 than during the 1890–1935 period (see figure 2). With the number of farms declining and aggregate output growing, average output per farm (one measure of size) grew rapidly. The average farm size was 1.6 times larger in 1940 than in 1890, but was 8.8 times larger in 1990 than in 1940. Since 1960 farms have also become more specialized in the products or outputs they produce.34

Notably, the index of aggregate real input under the control of U.S. farmers has not changed much over the past century (see figure 2), but the composition of the inputs has changed dramatically. Aggregate real input in 1990 is only slightly larger than in 1890, and larger growth in aggregate output is possible only with large productivity growth or technological change. Figure 3 displays trends in labor, land and building, farm machinery, and chemical use in agriculture from 1910 to
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Figure 2. U.S. (Real) Farm Output, Farm Input, and Total Factor Productivity, 1889–1990

Source: Adapted from Huffman and Evenson, Science for Agriculture, 183.

Figure 3. U.S. Aggregate Farm Input Use, 1910–1994 (1948=100)

1994. These data show a strong decrease in labor use, especially after 1950, and the changes are generally parallel to the reduction in the number of farms. At the same time, machinery and chemical input use increased; the land and buildings input remained largely unchanged over time. With relative input price changes that have occurred over this period, Gardner concludes that the large reduction in labor use in U.S. agriculture can only be explained by labor-saving technological change; that is to say, the new technologies generally use less labor to produce a given quantity of output at any given relative input price.\(^{35}\)

Although the trend in labor use in U.S. agriculture is strongly negative, labor’s share of production costs does not show a similar trend because real wage rates have been rising. The picture is further clouded by some estimates of factor cost shares that either ignore or grossly undervalue the time farm operators and other unpaid farm family members spent in farm work.\(^{36}\) However, if we value operator and unpaid family labor on an opportunity-cost basis and piece together information from a couple of studies that use roughly similar methodology, a fairly clear picture emerges. During 1910–1946, labor’s share of production costs in agriculture was between 55 and 62 percent without a strong trend. By 1948, the share was about 43 percent and trended downward to about 29 percent by the mid-1950s; from the mid-1950s to 1980, labor’s cost share in agriculture remained largely unchanged.\(^{37}\) Thus, it seems safe to say that labor’s cost share in U.S. agricultural production has been cut by 50 percent over the past century.

Agricultural production in the distant past was relatively labor intensive, but relentless technological change has changed all that. Much of the work has been mechanized or automated, extensive seed-bed preparation for field crops has been replaced by no-till planting, and modern pest control is accomplished by a combination of chemical, pharmaceutical, and biotechnical methods.\(^{38}\) Furthermore, new information technologies using computers, satellites, sensors, and geographical information systems have greatly advanced measurement possibilities for collecting data with spatial and temporal dimensions for physical and environmental conditions, input use, and crop
yields in agriculture. Compared to fifty or a hundred years ago, today’s farmers spend relatively more time in planning, analyzing, and managing their farm business and less in field work and livestock care. Hence, information acquisition and analytical and decision-making skills that are made possible with higher levels of formal schooling are increasingly important to successful U.S. farmers.

Changes in agriculture have also benefited the rest of the U.S. economy. The share of the U.S. labor force that was employed in agriculture was relatively large, 43 percent, in 1890. In 1910 it declined to 31 percent and to 21.5 percent in 1930. In 1950, 11 percent of the labor force was employed in agriculture, and the decline continued to 2 percent in 1990. Hence, a century ago only 57 percent of the U.S. labor force was nonagricultural; now it is more than 98 percent. Real prices received by U.S. farmers for their products have also fallen over this time period. For the period from 1948 to 1989, prices received by farmers for crop and livestock products relative to the general price index declined at an average rate of 1.9 percent per year. If we consider the period from 1910 to 1989, excluding the World War I and II years, real prices received by farmers declined at an average rate of 1.5 percent per year—which translates into large consumer welfare gains. Thus, the long-term decline of the share of the U.S. labor force in agriculture and of real prices received by farmers is largely due to the relatively rapid increase in agricultural productivity that shifted the supply schedule for farm outputs to the right faster than the demand schedule for farm outputs was shifting from the effects of population and real income growth. Furthermore, the productivity gains in agriculture that made possible a dramatic reallocation of the U.S. labor force and a decline in real food prices greatly aided the growth of cities and made possible a rising standard of living for the U.S. population.

U.S. SCHOOLS: LESSONS FROM THE SCIENCE OF AGRICULTURE

The past performance of U.S. public schools, especially since 1960, stands in stark contrast to that of U.S. agriculture. A school is an institution that produces local public services (i.e.,
the schooling of children in a relatively small geographic area), which has varied in size over time and cross-sectionally. Competition among schools is limited significantly by children being tied to a limited choice of schools within a short distance of their parents’ home. Formal schooling is part skill creation, part local culturalization, and part screening, and the relative importance of these components differs across countries, through grade levels, and over time.

Starting in about 1983, several reports detailed the declining performance of American schools. Although there has been much discussion of the state of American schools and some experimentation with curriculum, class size, teacher training, school size, school choice, and similar variables, the consensus is that little fundamental improvement of American schools has occurred, and furthermore, that the scientific knowledge base upon which decisions are being made is weak and poorly constructed.

The problems of U.S. schools and schooling seem to be related to the problems of schools and schooling in other English-speaking, high-income countries (particularly the United Kingdom and Canada). U.S. schools, however, face some special problems associated with ghetto (note the avoidance of using “high population density” or “urban”) life-styles. One common dimension of the problem of these public schools lies in unresolved issues about teaching methods. This arises from a failure of the educational R&D system to adequately formulate and test hypotheses about learning and teaching in schools and to build a stock of verified hypotheses (that is, the scientific knowledge base for schooling) that could help guide good schooling policy, school administration, and those involved in setting schooling policy. Indeed, it would seem that precisely the lack of such a knowledge base would tend to encourage school policymakers, educators, and parents alike to demand good information—and to proceed cautiously in making changes in the absence of conclusive evidence on the superiority of “new” teaching methods.

To simplify and focus the discussion, I emphasize a dichotomy between “progressive” and “traditional” teaching methods. Although they came into use without strong scientific evidence of their superiority, traditional methods of teaching and school
organization evolved over approximately a century of experience in elementary and secondary schools. Thus, they were largely a set of methods based on the refined art of teaching (that is, what seemed to work relatively well in a wide range of school locations) rather than the science of teaching or learning.

Although my characterization of competing teaching methods will undoubtedly do injustice to the teaching profession, teacher-training colleges, and educational philosophers, it will help fix ideas for the comments to follow. Under “traditional” teaching methods, learning is directed by the teacher (rather than the student), typically in whole-class learning activities for classes of relatively “equal” ability students. Teaching is systematically focused on important subjects. Students are in particular directed to learn basic knowledge, including arithmetic operations, phonics, grammar, and punctuation. Teachers’ expectations of students are relatively high, grading standards are stringent, and students from sixth grade on are expected to complete regular homework assignments and to perform well on formal and standardized tests.

Under “progressive” teaching, which has its origins in the 1960s and early 1970s, teaching is primarily “child-centered learning by discovery.” Students choose when and where to proceed in discovery. Classes consist of “mixed” ability students, and teaching is largely helping students choose individualized or small-group projects to complete and helping them with issues that arise. No emphasis is placed on teaching or learning important basic knowledge like phonics, grammar, punctuation, and arithmetic, or on information organized around subjects. Teachers’ expectations of students are relatively low, grading standards are informal or loose, homework is not regularly assigned, and students do not take formal or standardized tests.

The attempt to replace traditional teaching methods in public schools with progressive teaching methods over the past three decades reflects the unscientific nature of school administration, teacher education, and research in education and schooling. Before the 1960s, teacher colleges and teaching methods had a strong ideological bias in favor of egalitarianism and against streaming or forming relatively homogenous ability groupings of students (even when student populations were
large enough to permit forming them). This schooling philosophy seems never to have had a strong scientific basis, is socially cost-inefficient, and may have become a hindrance to recent progress in public schools. Furthermore, it contradicts the trend in successful modern industrial production practices where homogenous inputs are a key factor in the quality control of the output and in keeping costs of production low.

With roughly thirty years of time over which to accumulate strong evidence on various components of progressive teaching methods developed from Dewey, Piaget, Clegg, and others, the empirical evidence remains weak for widespread use of the following practices in public schools: mixed ability classes (versus grouping students by ability and streaming of students); child-centered learning by discovery (versus whole-class teaching and teacher-directed learning); wide-ranging, unstructured projects (versus material organized around individual subjects and essential knowledge); and children progressing at their own pace through distinct phases of learning, without teachers trying to speed up the pace (versus teachers having high expectations for students’ achievements and intervening with active teaching methods).46 In support of traditional methods, new research has shown that stringent grading standards and assigned homework are having a strong positive effect on the performance of U.S. schoolchildren.47

Why is there a weak scientific base to teaching methods? Education or schooling research now has a major advantage over agricultural research of a century ago because of the accumulation of a large body of core scientific knowledge and well-developed methods of experimental design and statistical methods, a dramatic fall in the price of data storage and computing, and a large number of individuals being trained at the Ph.D. level in related fields who could conduct schooling research, given the right incentives. Although science in general advances by providing researchers with the widest possible range of channels to discovery, critical evaluation of research output for the quality of discovery is absolutely essential, including its application of rigorous methods, logical reasoning, and strength of evidence for or against well-formulated hypotheses. Otherwise, the research does not accumulate over time.
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into a stock of useful knowledge. Hence, schooling research must greatly strengthen its scientific quality.

Schooling research and teacher education, however, seem to have been disadvantaged relative to agriculture by the establishment of public state teacher colleges often separate from the research-oriented public state universities. A key attribute of the evolution of higher education in the United States during the twentieth century was the linking of the diffusion of knowledge closely to the creation of knowledge. In this process, a university, a collection of colleges and possibly professional schools, became a production center where the research of one part enhanced the teaching and research of other parts. Thus, colleges within a university came to have a significant comparative advantage over free-standing colleges, including teachers' colleges, because they could exploit technical complementarities among their various components. Thus, the early state politics of instructional location may over the long term have placed schooling research at a major disadvantage for obtaining easy access to important advances in related sciences and scientific methods.

Schooling research, like agricultural research, must also carefully distinguish in its research and recommendations between methods that might work well under highly controlled experimental conditions and those that seem likely to work well when widely applied in the field—that is, broadly across a variety of public schools—given heterogeneity in teachers, students, and local needs for skills. In agriculture, new technologies that are unprofitable or marginally profitable are never widely adopted and do not change agricultural productivity. Although schools do not face price competition like farmers, schooling research should focus on discovering and recommending new methods that are grossly better than traditional ones, methods that can improve the performance of schoolchildren and graduates of secondary schools. This is the primary way of insuring that new recommended methods will significantly improve schooling quality (or reduce cost). Furthermore, feedback is needed from school administrators and teachers about what seems to work well and what does not work. When discoveries of new superior teaching methods are made, a major information dissemination
effort is needed to help school administrators and teachers understand the new methods and possibly overcome suspicion of their merits and motivations. Thus, research to develop successful teaching methods for public schools needs some teacher and school administrator input into the design, and considerable resources must be devoted to disseminating information about how and when to use them. Teachers, like farmers, are not trained in scientific research methods and cannot be expected to conduct original schooling research, although they may usefully participate in it.

When schooling research discovers superior new teaching methods, it makes some past discoveries and methods obsolete. Thus, although progressive teaching methods may have always been inferior for widespread use in public schools, a return to traditional teaching methods will not be the long-term solution to superior teaching methods either. Hence, successful research creates obsolescence and the need for selective change in schooling as in agriculture.

The impact of agricultural research and its credibility was undermined in the early years when different research institutions produced conflicting findings. Research into education and schooling that is poorly designed, executed, and evaluated does little to improve the quality of teaching, and to the extent that inferior new teaching methods get adopted by schools, they most likely lower schooling quality and the achievement of schoolchildren. They may also eventually undermine public confidence in new teaching methods and possibly in public schools.

As new legislation has strengthened intellectual property rights to innovations, the private sector has found it profitable to undertake a broader range of agricultural research and development activities. This has provided competition for public agricultural research institutions. The public sector continues, however, to be an important funder and performer for research in pretechnology and general or core sciences. With public confidence in U.S. public schools being undermined by the implementation of questionable teaching and school-administration practices, and with changes occurring in the distribution of tastes for schooling and extracurricular activities by parents,
political interest groups have successfully won new state and federal legislation that enables new "schooling" institutions (e.g., home schooling, charter schools, sectarian schools) to operate. These new institutions, along with the existing private (largely church-affiliated) schools, seem poised to train an increasing share of the school-aged students during the next decade. Although this competition may weaken public schools in the short term, it seems likely to create the incentives needed to make the public-school systems in the United States undergo additional soul-searching and perhaps lead them to increased demand for high-quality research and information on schools and schooling. Over the long term, the public schools can become stronger. However, it seems unfortunate that poor decisions about teaching and school administration practices have caused so many needless changes.

Schooling quality is an important attribute of a year of schooling, but it is difficult to judge. In the United Kingdom, the public's dissatisfaction with schooling quality reached the point in 1988 that new legislation was enacted establishing a national curriculum and accompanying national tests for pupils aged seven, eleven, and fourteen. This legislation represented a major attempt to establish common performance standards by which all students and schools could be evaluated. In 1991 the British Ministry of Education conducted an evaluation of alternative teaching methods and concluded that learning-by-discovery was failing badly in primary schools. In response, the ministry urged a return to traditional teaching methods. To hasten this move, a new inspectorate of public schools, Ofsted, was created in 1992. Its job is to inspect the teaching methods and performance of primary schools, and the inspector has continued a broad campaign against sloppy, progressive-inspired teaching methods.

In the United States there is a long history of local and state control of schooling policy. Although this system served the country well for its first two hundred years, the rapid growth in service-sector employment, the demand for educated labor, and the emergence of a national labor market for individuals with higher education and a high frequency of interstate mobility have greatly changed the political-economic environment
for schooling policy. The appropriate political jurisdiction for making schooling policy may have grown extensively beyond the boundaries of localities and states; state-government control of schooling policy is no longer socially efficient in the United States.

Finally, teacher colleges have for many years entertained a strong ideological bias against grouping and streaming students in public schools. One can speculate that this ideology is also rooted in the unscientific nature of schooling research—that is to say, the inability of schooling researchers to conceptualize and statistically test models of behavior where relationships are complex and outcomes are uncertain or risky. If the classification methods used by school administrators and teachers for grouping students frequently place them in the "wrong" group, there is a socially undesirable cost of grouping or streaming. Research on improved methods for grouping can and should increase the share of "correctly" placed students, but it may involve significant research in the complex area of child development, the production of competencies in young adults, and the adoption of methods from economics and statistics for dealing with decision-making under conditions of uncertainty, including principal-agent models.

Over the long term, technical change in public schooling has been slow, and it sometimes seems to have been technological regress rather than progress. The future international competitiveness of the United States hinges on U.S. schools finding a route to steady technological and institutional progress.

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ENDNOTES


7 Huffman and Evenson, *Science for Agriculture*, chap. 1.


9 Huffman and Evenson, *Science for Agriculture*, 93–95.


12 Ibid., 25.

13 Ibid., 61.

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15 Fuglie et al., “Agricultural Research and Development.”


17 Huffman and Evenson, Science for Agriculture, 65.


20 There are different scholarly views about the role of input prices in inducing a particular type of technological change. See Hayami and Ruttan, Agricultural Development, 55–63, and Olmstead and Rhodes, “Induced Innovation in American Agriculture,” for opposing views.

21 See Huffman and Evenson, Science for Agriculture, chap. 6.


25 Huffman and Evenson, Science for Agriculture, 140, and Wallace E. Huffman and Robert E. Evenson, “The Development of U.S. Agricultural Research and Education: An Economic Perspective,” Department of Economics, Iowa State University, 1994, summarize data on the numbers of U.S. patents granted in particular agricultural technology fields (or patent classes) by decade covering more than one hundred years.


27 Huffman and Evenson, Science for Agriculture, 182–183; also see figure 3.
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30Griliches, “Issues in Assessing the Contribution of Research and Development to Productivity Growth.”


32Huffman and Evenson, Science for Agriculture, chap. 6.

33Ibid. and other studies have shown that a significant share of TFP (or technical) change in U.S. agriculture is related to past investments in research and development.


35Gardner, “Changing Economic Perspective on the Farm Problem.”


37Ibid.


40Huffman, “Education and Agriculture.”


See Huffman and Just, “The Organization of Agricultural Research in Western Developed Countries.”

Editorial Staff, “Plowden’s Progress: The ‘Progressive’ Revolution in Britain’s Schools is Being Reversed.”

For example, see Goldin and Katz, “Human Capital and Social Capital.”
