



The Drivers of U.S. Agricultural Productivity Growth

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Over the past 100 years, productivity growth in U.S. agriculture radically reshaped the country's farm sector and its role in the national economy. In 1900, agricultural output constituted 15.5 percent of U.S. GDP, and it took 5.7 million U.S. farms and 37.9 percent of the national labor force to feed and clothe 76 million U.S. consumers: a consumer-to-farmer ratio of 13:1. By 2017, agriculture had shrunk to 0.9 percent of GDP and the farm labor force to 1.1 percent of the national total. While the number of U.S. consumers had grown to 325 million, the number of farms had shrunk to just 2.0 million, increasing the consumer-to-farmer ratio to 159:1.

U.S. agricultural output increased, in aggregate, 4.6-fold from 1910 to 2007.¹ The mixture of inputs changed dramatically. U.S. farms now use greater quantities of purchased inputs (such as seed, energy, and chemicals) than they did a century ago and much less labor: labor use in agriculture fell by 80 percent. With these opposing trends

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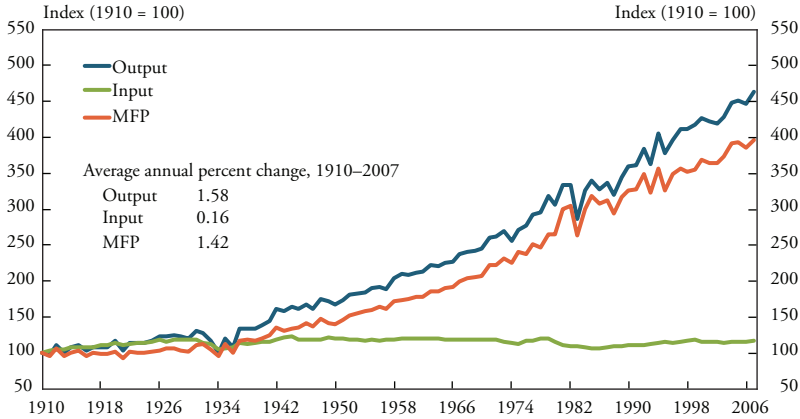
balancing each other, aggregate input use overall increased little (Alston and Pardey 2020). Hence, multifactor productivity (MFP)—the aggregate output relative to the aggregate of measured inputs—increased 3.5-fold, growing on average by 1.42 percent per year from 1910 to 2007.

How can U.S. agriculture now produce so much more output per year with little overall change in the measured use of inputs? The story is complicated. Fundamentally, major labor- and land-saving innovations and the associated structural transformation of agriculture were facilitated by public and private investments in research and development (R&D) and incentivized by changes in the broader economy. But these processes involved complex cause-and-effect relationships that are hard to disentangle.

Our account of the drivers of long-term productivity growth in U.S. agriculture focuses first on the direct role of R&D-driven growth through the stock of scientific knowledge.² We then turn to the roles of technological innovation and the structural transformation of agriculture—farm size, specialization, what crops are grown where and when, how resources are used, and the roles of off-farm employment and part-time farming. We highlight the uneven evolving time path of U.S. agricultural productivity—in particular, a significant midcentury surge followed by a slowdown—which helps us as we try to identify the relative roles of different drivers at different times. We conclude the paper by considering the prospects for U.S. farm productivity growth in the face of emerging economic and environmental headwinds.

I. The Long-Run Pattern of MFP Growth

From 1910 to 2007, the index of the aggregate quantity of output (Q) grew at an average rate of 1.58 percent per year. Meanwhile, the index of the aggregate quantity of inputs (X) used in U.S. agriculture grew by just 0.16 percent per year, reflecting some increases in inputs of capital and materials that offset the reductions in the use of land (after the late 1970s) and especially labor. Consequently, the measure of MFP ($MFP = Q/X$) grew at a long-run average rate of 1.42 percent per year (Chart 1). This implies that U.S. agriculture produced 4.6 times as much aggregate output in 2007 as in 1910, without appreciably increasing the quantity of aggregate input.

Chart 1**Quantity Indexes of Output, Input, and MFP, U.S. Agriculture, 1910–2007**

Source: Abridged version of Figure 1 in Pardey and Alston (forthcoming).

The long-run path was not always smooth—secular changes in productivity growth are confounded with year-to-year variations related to weather and other transitory factors. Table 1 shows growth rates in U.S. MFP by decade for the period 1910–2007. Rates of MFP growth have varied considerably from decade to decade, with relatively high rates of growth during the period 1950–80—when the rate of growth of aggregate output was also relatively high—and relatively slow rates of growth since then.

Using essentially the same data, Andersen and others (2018) estimate various trend models and strongly reject the hypothesis of a constant growth rate. Their results support the view that U.S. farm productivity growth has slowed in recent decades, but they also suggest that this slowdown came after a period of unusually rapid productivity growth. MFP grew by 1.42 percent per year for 1910–2007, but this long-term average reflected a period of below-average growth at 0.83 percent per year for 1910–50, above-average growth at 2.12 percent per year for 1950–90, and again below-average growth at 1.16 percent per year for 1990–2007.

Using state-specific and regional data for the period 1949–2007, Table 2 reveals that higher-than-average rates of output growth in some regions (for example, the Pacific and Northern Plains regions) were associated with correspondingly higher-than-average growth rates of

Table 1
Annual Average U.S. Farm and Nonfarm Private Business MFP Growth Rates, 1910–2007

Period	Private business sector MFP growth		Agricultural GDP as a share of GDP	Farm labor share of total
	Nonfarm	Farm		
	(percent per year)		(percent)	(percent)
1910–20	1.61	0.21	15.8	27.4
1920–30	1.56	-0.07	9.9	23.1
1930–40	2.52	1.71	7.5	22.9
1940–50	2.05	1.47	7.3	15.9
1950–60	1.31	2.25	4.8	10.8
1960–70	1.76	1.69	2.8	6.6
1970–80	0.88	2.46	2.5	4.1
1980–90	0.55	2.08	1.7	2.7
1990–2000	0.97	1.25	1.3	1.7
2000–07	1.39	1.03	1.0	1.4
1910–50	1.93	0.83	10.2	22.3
1950–2007	1.13	1.83	2.4	4.8
1910–2007	1.46	1.42	5.6	12.0

Notes: All MFP growth rates represent averages of annual (year-over-year) rates for the respective periods calculated by the log-difference method. Labor includes the number of full-time equivalent employees plus the number of self-employed persons and unpaid family workers. Shading indicates the decades with growth rates above the long-term (1910–2007) average.

Source: Abridged version of Table 2 in Pardey and Alston (forthcoming).

input use. The Pacific, Northern Plains, and Southern Plains regions recorded somewhat higher regional productivity growth rates; the Central, Mountain, and Northeast regions somewhat lower. However, each region experienced solid productivity growth on average during the period 1949–2007—average annual productivity growth ranged between 1.54 and 2.05 percent per year among regions—and a slowdown.

The regions and states within them are quite diverse in relevant respects. In the Northeast, input use shrank considerably while output grew comparatively little. For the Southeast, Central, and Southern Plains regions, aggregate input use also declined against solid output

Table 2
Regional and National Input, Output, and Productivity Growth Rates, 1949–2007

Region	1949–2007			MFP by decade							
	Input	Output	MFP		1949–60	1960–70	1970–80	1980–90	1990–2000	2000–07	
			Mean	Max.							
(percent per year)											
Pacific	0.54	2.32	1.79	1.66	1.95	1.26	2.29	3.10	1.48	1.15	1.36
Mountain	0.48	1.68	1.20	0.49	2.05	1.55	1.72	1.60	1.46	1.13	-0.92
Northern Plains	0.15	2.20	2.05	1.75	2.36	2.76	1.27	1.65	3.60	1.28	1.46
Southern Plains	-0.21	1.82	2.03	1.16	2.94	2.08	2.63	2.09	2.29	1.40	1.56
Central	-0.24	1.38	1.61	1.32	1.90	1.40	1.03	2.77	1.67	1.48	1.23
Southeast	-0.46	1.26	1.72	0.97	2.69	2.07	2.00	2.74	2.42	0.74	-0.27
Northeast	-1.08	0.46	1.54	1.03	2.22	2.75	2.74	0.94	2.01	-0.29	0.67
United States	-0.07	1.70	1.77	1.77	1.77	1.89	1.69	2.46	2.08	1.25	1.03

Notes: All growth rates represent averages of annual (year-over-year) rates of the respective periods calculated by the log-difference method. Shading indicates the decades when growth rates peaked. The regions are as follows: Pacific—California, Oregon, Washington; Mountain—Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming; Northern Plains—Kansas, Nebraska, North Dakota, South Dakota; Southern Plains—Arkansas, Louisiana, Mississippi, Oklahoma, Texas; Central—Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Wisconsin; Southeast—Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, West Virginia; Northeast—Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
Source: Calculated by the authors using Version 5 of the In\$TEPP Production Accounts.

growth (albeit much less than in the Northeast). In the other regions both inputs and outputs grew, and for the Pacific region MFP growth reflected greater-than-average input growth but even greater output growth. The timing of the surge in MFP growth varied among regions. In the Northeast and Southern Plains regions, MFP growth peaked a decade or two ahead of the national peak in the 1970s, shared with the Pacific, Central, and Southeast regions; in the Northern Plains, it peaked a decade later, in the 1980s.

Agricultural and economy-wide MFP growth

During the first half of the twentieth century, relatively rapid growth of the nonfarm sector came partly at the expense of the farm sector—especially by attracting labor away from farms—with implications both for labor-saving innovations on farms and the growth rate of farm productivity as well as for the farm share of the total economy (Kendrick and Jones 1951). In the early 1900s, agriculture employed more than one-third of the national workforce: rural-urban migration mattered, and changes in agricultural productivity had meaningful effects on national productivity measures. By the early 2000s, agriculture’s share of the economy had shrunk to the extent that changes in agriculture had little consequence for economy-wide measures of economic performance.³

These connections are reflected in the measures of U.S. farm and nonfarm private business MFP growth reported in Table 1. The long-term (1910–2007) annual average MFP growth rate for the farm sector was 1.42 percent per year. However, during the period 1910–50, MFP grew in the nonfarm sector by 1.93 percent per year on average, more than twice the rate for the farm sector, 0.83 percent per year. And for 1950–2007, these roles were reversed: MFP grew by 1.83 percent per year in the farm sector but just 1.13 percent per year in the nonfarm sector.

Table 1 shows that U.S. nonfarm productivity growth accelerated in the 1910s and 1920s, peaked in the 1930s and 1940s, and began to slow appreciably in the 1950s, with a sharp drop in the 1970s. Hence, for the nonfarm sector, annual average MFP growth rates exceeded the long-term (1910–2007) average for the 1910s through the 1940s and in the 1960s, and they have been below the long-term average from the 1970s on. Farm productivity followed a similar pattern two

decades later, with above-average productivity growth rates for the 1930s through the 1980s. Combining these two elements, and noting the further decline of the farm share of the total economy, helps account for the surge in national MFP growth during the 1920s through the 1960s. Farm productivity growth rates remained high into the 1970s and 1980s, well above their nonfarm sector counterparts, but by then the farm share of the economy had shrunk to just a few percent—too little to be of much consequence in sustaining the national productivity growth rate.⁴

At the start of the twentieth century, agriculture accounted for one-sixth of U.S. GDP, while employing a much larger share of the national labor force—more than one-third. Over the course of the twentieth century, the rest of the economy grew much faster, and agriculture's share of GDP shrank by a factor of 15: from 15 percent in 1900–10 to 1 percent in 2000–07. Agriculture's contribution to GDP grew in real terms, though its share was shrinking. The farm-sector share of the total labor force fell by a factor of 24: from 34 percent in 1900–10 to 1.4 percent in 2000–07. The shrinking of farm labor as a share of the total labor force reflects a decline in the total labor use in agriculture. Total private employment of labor increased fourfold, while employment of labor on farms shrank sixfold.

II. The Radically Changed Realities of U.S. Agricultural R&D

The U.S. agricultural R&D landscape has undergone seismic shifts in recent decades. The balance of R&D spending has moved away from agriculture, away from the public sector, and even away from the United States itself. Critically, public investments in agricultural R&D are now on the decline (in both nominal and inflation-adjusted terms), with a dramatic downsizing in the share of that spending directed toward preserving or promoting agricultural productivity gains.⁵

In 1960, the United States accounted for 20 percent of global investments in public agricultural R&D, most of which were carried out by agencies such as the U.S. Department of Agriculture (USDA) and the Land Grant Universities (Pardey and others 2016a, 2016b). Fast-forward to 2015—the latest year of available global data—and the picture is very different. The U.S. share of the global public-sector total has fallen to 8.9 percent, now second to the 14.5 percent (purchasing

power parity) share contributed by China. In 1996, China, India, and Brazil—three agriculturally large, middle-income countries—collectively overtook the United States in public agricultural R&D spending, and by 2015, together they spent an estimated \$3.16 on public agricultural R&D for every \$1.00 invested in U.S. public agricultural R&D.

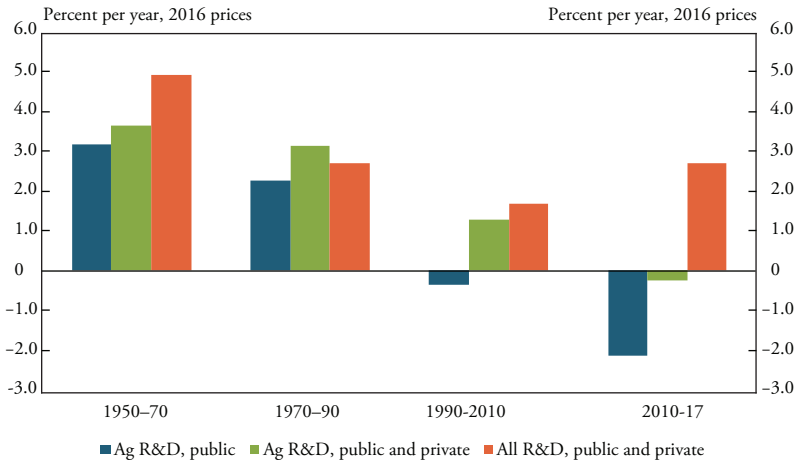
How did this happen? Since at least the middle of the twentieth century, real (inflation-adjusted) spending on U.S. public agricultural R&D grew at an ever-declining rate (Chart 2). Even more critically, starting around 2002, the United States began cutting back, not just slowing down, the rate of growth of spending on public agricultural R&D investments. By 2015, aggregate U.S. spending on agricultural (net of forestry) R&D had retreated to the inflation-adjusted levels that prevailed in 1972. In marked contrast to the U.S. retreat from investments in public agricultural R&D, Brazil, India, and especially China have been ramping up their investments in public agricultural R&D, especially in the decades since 1990.

Chart 3 reveals several other notable features of the changing R&D realities facing U.S. agriculture. First, the growth in private investments in agricultural and food R&D has consistently outpaced the growth in public spending since the 1950s, such that the public share of U.S. agricultural and food R&D shrunk from 65.1 percent of the public and private total in 1950 to just 31.3 percent in 2017. Second, like public spending on agricultural and food R&D, private spending on agricultural and food R&D by mainly publicly listed firms has ratcheted down, slipping into negative terms in the past decade. Third, total (public and private) R&D spending for food and agriculture grew at a slower rate than overall R&D spending, thus shrinking the food and agricultural share of total U.S. R&D spending from 3.5 percent in 1950 to 2.3 percent in 2017.

Who foots the public agricultural R&D bill?

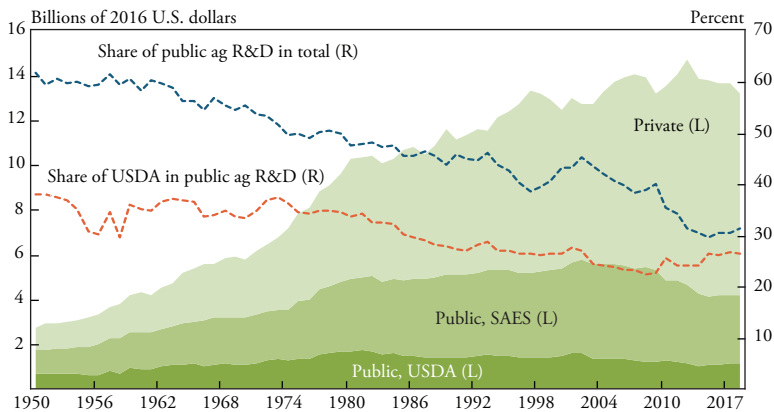
USDA agencies have long relied on federal funding allocated by way of the Farm Bill to carry out research. However, over time, funds from USDA agencies have shrunk as a share of the total pool of public funds directed to agricultural R&D. The State Agricultural Experiment Stations (SAESs)—typically co-located on the campuses of the Land Grant

Chart 2
Whittling Away Investments in U.S. Agricultural R&D, 1950–2017



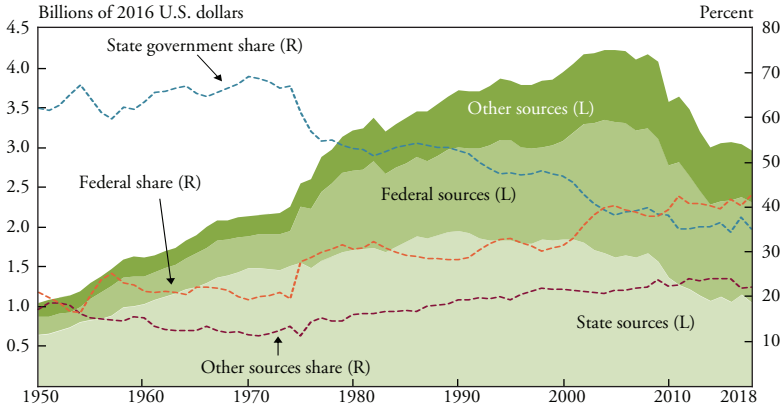
Notes: Public agricultural R&D includes SAES and USDA intramural spending, excluding forestry research. The series were deflated using an agricultural R&D deflator from InSTePP. All growth rates represent averages of annual (year-over-year) rates of the respective periods calculated by the log-difference method. Gross domestic expenditure on R&D (GERD) data begin in 1953, so the growth rate for the first period is for 1953–70. Sources: Unpublished InSTePP data. The SAES R&D series (excluding forestry) are compiled from unpublished USDA Current Research Information System (CRIS) data files. The USDA intramural series for years prior to 2001 are also from the USDA sources cited in Alston and others (2010, Appendix III) and the National Science Foundation (NSF) thereafter.

Chart 3
Trends in Public and Private Investments in U.S. Agricultural R&D, 1950–2018



Sources: Unpublished InSTePP data. The SAES R&D series (excluding forestry) are compiled from unpublished USDA CRIS data files. The USDA intramural series for years prior to 2001 are also from the USDA sources cited in Alston and others (2010, Appendix III) and the NSF (various years) thereafter.

Chart 4
Shifting SAES Funding Sources, 1950–2018



Sources: Unpublished InSTePP data. The SAES R&D series (excluding forestry) are compiled from unpublished USDA CRIS data files. The USDA intramural series for years prior to 2001 are also from the USDA sources cited in Alston and others (2010, Appendix III) and the NSF (various years) thereafter.

Universities—conduct the majority of U.S. public agricultural R&D: 73.4 percent in 2017, up from 61.4 percent in 1950 (Chart 4).

The sources of financial support for SAES research are more diversified and have changed dramatically over time. The state government share of funding for SAES research fell dramatically; from 69.3 percent in 1970 to just 35.2 percent in 2018 (Chart 4). Federal funding picked up much of the shortfall and now accounts for 42.7 percent of overall SAES funding, more than double its share in 1970. Subtly, but importantly, Farm Bill funding made available to the SAESs by way of the USDA fell markedly as a share of total federal funding to the SAESs over the past several decades: from around three-quarters in the mid-1970s to two-thirds in 2018. The increase in federal funding to the SAESs—from 27.7 percent of total SAES funding in 1975 to 42.7 percent in 2018—stemmed from an increase in mainly competitive, grant-allocated funds coming from agencies such as the National Institutes of Health, National Science Foundation, Department of Energy, Department of Defense, and the U.S. Agency for International Development. Notably, the share of SAES funding from a variety of other sources (including earned income, private sources, and other nonfederal sources) has risen steadily since the 1960s and now constitutes 22.1 percent of total SAES funding.

A reduction in productivity-oriented research

Along with the reduction in state government- and USDA-sourced federal funding, SAES research priorities have also shifted—most notably, to reduce research aimed at preserving or promoting farm productivity. A little over one-half of SAES research spending (53.3 percent) in 2018 was directed to agricultural productivity pursuits, down from the almost two-thirds (64.6 percent) share in 1976. The SAES research agenda has increasingly focused on food safety, food security, and environmental concerns, programs of research that have little if any effect on enhancing or maintaining farm-level productivity. No doubt these other areas of research have social value, but their expansion has been at the expense of, not in addition to, productivity-oriented R&D.

The reduction in emphasis on productivity-oriented R&D has been pervasive throughout the SAES system. In 1976, 37 of the 48 contiguous states directed at least 60 percent of their agricultural R&D spending to productivity-related issues. By 2018, only 10 of those 48 states exceeded the 60 percent productivity threshold, with 14 of them directing less than 45 percent of their agricultural research effort to productivity-related topics.

III. Farm Productivity Drivers

What accounts for the twentieth-century surge and slowdown in U.S. farm productivity? In a recent study, we present a range of evidence related to potential drivers of U.S. farm productivity patterns (Pardey and Alston, forthcoming). We suggest that innovations on farms and the associated structural changes are the proximal causes, while public and private investments in agricultural R&D are a more fundamental source of innovation on farms. We conclude that agricultural R&D spending patterns could account for the more recent slowdown, but not the midcentury surge. We posit that the sluggish adjustment associated with the “farm problem” could account for the mismatched timing between the adoption of innovations and the resulting productivity surge.⁶ We find a strong temporal concordance between changes in the structure of farming and patterns of productivity growth.

Agricultural R&D and knowledge stocks

In conventional and widely applied models, current agricultural productivity depends on an agricultural R&D knowledge stock created from investments in agricultural R&D over many years. As described and documented by Alston, Craig, and Pardey (1998), Alston and others (2010, 2011) and Huffman and Evenson (1993, 2006), among others, it takes a long time for agricultural R&D to influence production (the lags in the creation of new knowledge and adoption of technology are long), and then it can affect production for a long time. However, the effective stock of agricultural knowledge becomes obsolete as new technologies embodying new knowledge are developed, or the stock depreciates because of changes in the economic and environmental circumstances in which that knowledge or technology is used—attributable to coevolving pests and diseases and changes in climate or relative prices.

Using widely applied models that link agricultural R&D and productivity, we create measures of knowledge stocks arising from U.S. public agricultural R&D (Alston and others 2010; Huffman and Evenson 2006; Pardey and Alston, forthcoming). We show that these knowledge stocks grew, but at a monotonically declining rate throughout the relevant historical period. This pattern is consistent with the recent slowdown but not with the earlier surge in agricultural productivity, which would have required an R&D funding pattern that caused a commensurate surge in the growth of the stock of knowledge.

Along with the consequences of a decades-prior slowdown in agricultural research investments, a slowdown in agricultural productivity growth might also reflect a change in the effectiveness of those investments. The decline in the productivity share of agricultural R&D, described above, is equivalent to a 20 percent reduction in the effective quantity of productivity-oriented R&D spending for a given total expenditure. Although this is a relevant consideration, most of this shift has been relatively recent and too late to have contributed much to a productivity slowdown beginning a decade or two earlier, once we allow for R&D lags.

A second possibility is decreasing returns to agricultural R&D. It may be increasingly difficult to generate a further proportional gain in productivity on top of past productivity gains for several reasons. First, we may be getting closer to the biological potential of plants and animals

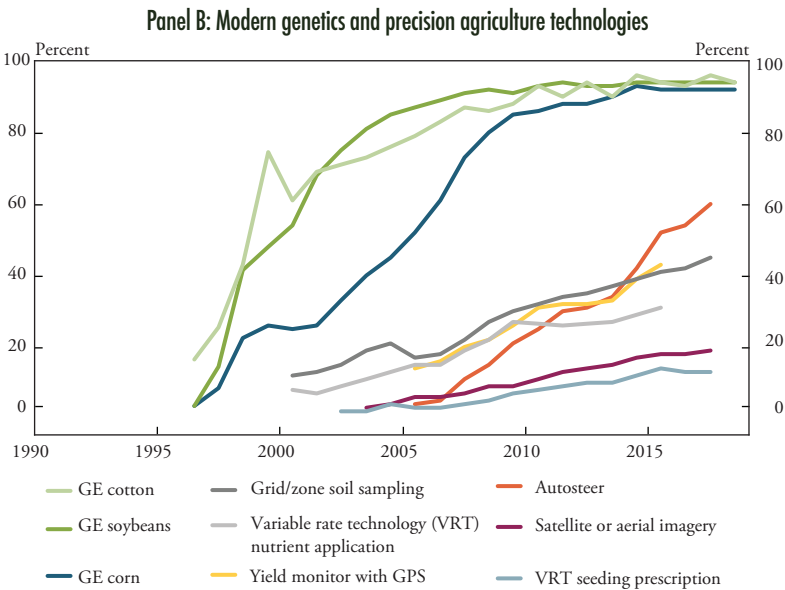
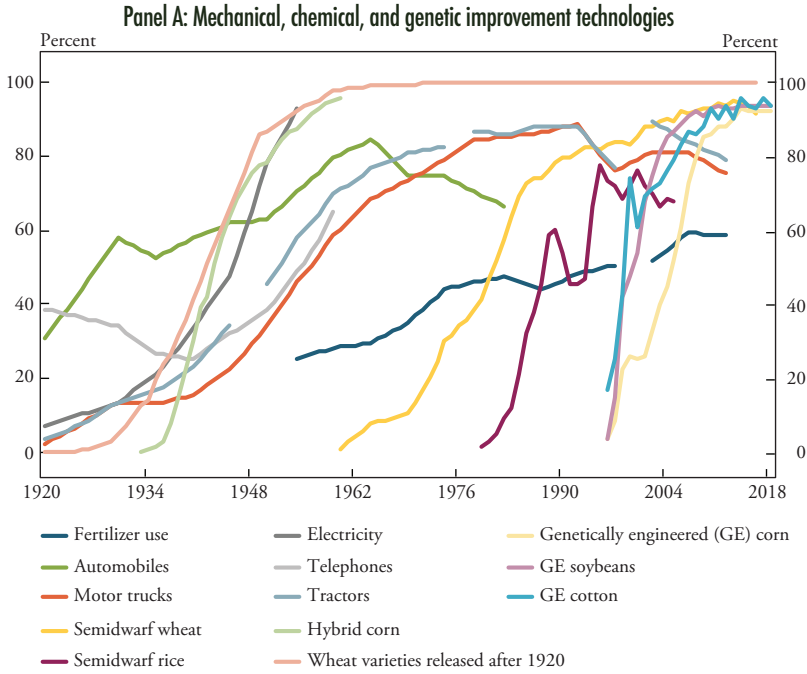
(see, for example, Fischer, Byerlee, and Edmeades 2014). Second, we might have to spend a larger share of the research resources maintaining past gains (see, for example, Ruttan 1982). Third, as discussed by Pardey and Alston (forthcoming), some suggest the easy problems have already been solved. However, studies of the rate of return to research investments provide direct evidence contradicting the pessimistic view. Rao, Hurley, and Pardey (2019) report the results from a meta-analysis encompassing 492 studies published since 1958 that collectively reported 3,426 estimates of rates of return to agricultural R&D. They conclude that “the contemporary returns to agricultural R&D investments appear as high as ever” (Rao, Hurley, and Pardey 2019, p. 37). Improvements in the technology of science and in the human capital of scientific researchers have made research more productive, and it seems these gains in research productivity have been sufficient to offset any decline caused by other factors.

Adoption of farm technologies

One plausible idea is that—like Gordon’s (2000) assessment of the “big wave” surge in U.S. MFP—perhaps we could account for the “big wave” surge in the rate of agricultural output and MFP growth in terms of the timing of waves of adoption for several major classes of agricultural innovations (Chart 5). A series of mechanical innovations transformed U.S. agriculture, including tractors, mechanical reapers, combines, and related bulk-handling equipment, which progressively replaced horses and other draught animals and much human labor. These innovations were particularly pronounced in the early decades of the twentieth century. As well as these on-farm changes, farmers benefited from improved technology for long-distance transportation of farm output (including refrigeration and preservation technologies), coupled with investment in roads, railroads, and other public infrastructure (such as those related to rural electrification, telephone service, and irrigation projects).

Biological innovations, in particular improved crop varieties that were responsive to chemical fertilizers, took center stage a little later, as illustrated by hybrid corn. In parallel with these genetic changes was the development of modern agricultural chemicals, including various fertilizers, pesticides, herbicides, antibiotics, and hormones, many of

Chart 5
Waves of Adoption of U.S. Farming Innovation, 1920–2018



Note: Adoption rates represent shares of farms or farm area adopting.
 Source: Alston and Pardey (2020).

which came after World War II. These were largely private innovations and interlinked with private and public investment in complementary varietal innovations (for example, herbicide-tolerant crop varieties). More recently, much agricultural innovation has emphasized information technologies, including various applications of computer technologies, geographic information systems and related precision production systems, and satellites and various remote- and ground-sensing technologies. Adoption processes for these digital farming technologies are still in their early and slow stages, apart from relatively simple technologies—such as GPS-based remote-sensing and guidance systems—that involve neither large investments in specialized equipment or human capital, nor major changes in farming systems and practices (see Alston and Pardey 2020).

We use data on adoption rates (shares of farmers or farm area adopting) for major examples of each of the categories of innovation to compare the time path of innovation with the time path of MFP (Pardey and Alston, forthcoming). We conclude that the timing of the adoption processes is consistent with our story about a slowdown in the rate of adoption of innovations contributing to a slowdown in productivity, but it does not clearly concord with a surge in the middle tercile of the twentieth century (1940–80). However, the productivity-enhancing consequences of innovation might lag considerably behind the evidence on initial adoption. Just as there is a lag between investing in research and developing technology, there is a lag between the release and initial adoption of technology and its ultimate impact on productivity, with due allowance for the role of adaptation of technology to better match particular contexts. During the in-between time in the middle of the twentieth century, while some farmers had adopted innovations and flourished, many others lagged and fell behind. Those who were slow to adjust and exit agriculture contributed to what became known as the “farm problem.”

Structural transformation

The farm problem—excess capacity in agriculture, especially too many farmers—was eventually resolved through consolidation of farms into more economic-sized units, specialized in particular outputs. This consolidation was enabled and promoted by the adoption

of innovative technologies, especially labor-saving machines, that enabled considerable economies of size with respect to land and required much less labor to efficiently operate a larger farm area. It took time for the farm sector to absorb these changes and capitalize on the associated efficiencies such that, during the decades following the first introduction of those innovations, American agriculture faced a serious adjustment problem: how to move resources out from agriculture, especially labor, that were earning very low returns in farm production where they were “stuck.”

Much of the measured productivity gains, especially in the earlier period, can be attributed to labor-saving innovations that facilitated the consolidation of farms into fewer and larger units. Using newly compiled national- and state-level data on the number and size distribution of farms, we show that much of the agricultural transition took place in the middle of the century, between 1930 and 1970 (Pardey and Alston, forthcoming). This transition was accompanied by an acceleration in farm productivity growth, associated with an acceleration in the rate of farmers exiting the industry, enabling a consolidation of farms into larger operations (see also MacDonald, Hoppe, and Newton 2018 and MacDonald 2020). More recently, the pace of farm consolidation has since returned to what seems to be a more normal, long-term rate commensurate with long-term productivity growth in the economy more generally. Using his measure based on the midpoint of the farm size distribution, applied to U.S. data for 1987–2017, MacDonald (2020) shows that the rate of farm consolidation has been fairly constant over time and across industry sectors for the past 30 years.

Farm size, specialization, and location

As farm size increased, farming also became more specialized. In addition, where that farming occurred also shifted. Both these specialization and spatial movement processes had—and continue to have—considerable consequences for agricultural productivity.

Increasing specialization in U.S. agriculture is evident at both the farm and state levels. Macdonald, Hoppe, and Newton (2018, p. iv) note that, “While few farms specialize in a single crop, field crop operations increasingly grow just 2 or 3 crops, versus 4–6 crops previously. Livestock production continues to shift toward farms that produce no

crops, and instead rely on purchased feed.” Analyzing state-level specialization trends over the period 1949 to 2006, Alston and others (2010) note that only three states increased the number of agricultural outputs produced, while seven states produced 10 fewer outputs toward the end compared with the beginning of the period. In fact, the majority of the states produced fewer outputs in more recent years, particularly in the Northeast, Pacific, and Mountain regions.

Agriculture involves a large physical footprint, occupying 44 percent of total land area in the United States in 2017. Agricultural production also involves biological processes that make it especially sensitive to the spatial variation in natural or environmental factors (such as soil and sunlight) that are intensively used by the sector. Hence, our measures of productivity can reflect changes in the context in which agricultural production takes place either because of changes in the environment in a given location (changing pests, diseases, or climate, for example) or because of changes in the location of production.

Beddow and Pardey (2015) show that the centroid of U.S. corn crop production moved 279 kilometers north and 342 kilometers west over the period 1879–2007. Changing the location of the crop changes the climate relevant for that crop. In addition, the use of shorter-duration corn varieties (an embodied form of technical change) not only enabled this spatial movement, but also gave farmers greater flexibility in their planting date decisions at any given location. Using phenological measures of climate (specifically temperature and soil moisture) that reflect changes in both the location and timing of corn production throughout the twentieth century, Beddow, Pardey, and Hurley (2014) show that the sensitivity of corn yields to unfavorable weather has declined over time. In this instance, embodied and unembodied technological changes have muted the detrimental productivity consequences of the variability of weather over time.

Physical and regulatory environments

Environmental factors could have contributed to the surge and slowdown in measured productivity growth. In terms of the physical environment, climate change, invasive pests and diseases, evolving pesticide resistance, and declining natural resource stocks could all have contributed to a more challenging physical and economic environment

for agricultural production, adding to the demands for maintenance research just to keep yields from falling and costs from rising.⁷ In addition, the economic environment for producers—including regulations governing production practices on farms—has become more difficult in some ways that may help account for the observed productivity patterns. The story reflects both environmental externalities that are not reflected in our MFP measures and the effects of policies that address those externalities.

Pesticides illustrate the main ideas here. The surge of farm productivity growth immediately following World War II was associated with a surge in the use of agricultural chemicals, especially synthetic fertilizers and pesticides (Pardey and Alston, forthcoming). Conventional measures of productivity growth do not account for the negative externalities associated with these agricultural chemicals, and in this sense, our measures overstate the true gains in productivity. The past 50 years have seen increasing public concern over the environmental consequences of agricultural pesticide use and greater environmental regulation of agricultural production. Many pesticides have been banned. A direct consequence of these regulations has been to reduce agricultural productivity—both measured and actual. Similar thinking applies to the development of intensive livestock production systems and the progressive, increasingly stringent regulation of the use of antibiotics, hormones, and other veterinary medicines, and the regulation of other production practices. Together, these aspects might have contributed both to the measured surge (reflecting unmeasured externalities or unmeasured consumption of poorly priced natural resource stocks that contributed to overestimated productivity growth) and to the subsequent slowdown (reflecting the consequences of regulations that internalized some of those costs). It is not easy to guess at the empirical importance of these aspects, but they are surely part of the story.

IV. Looking Forward

In the current agricultural environment, demands for private investments in innovation are being influenced by government through the prospect of new regulations (or taxes) applied to agricultural production—including technological regulations and environmental regulations to reduce greenhouse gas emissions and other spillovers from

agriculture—and through the influence of policy on the supply of farming inputs (especially labor and water) and on the markets for farm products.

This paper documents a significant downsizing of public support for agricultural R&D and a major decline in the share of that research devoted to preserving or promoting productivity growth. This shift in support for public sector R&D (in terms of both total investment and the balance of investments) reflects a changing role of scientific evidence in policy and shifting public preferences (Alston, forthcoming). Agricultural R&D investments are being scaled down even though meta-evidence shows that past U.S. investments in R&D have yielded very favorable returns: median reported benefit-cost ratios are in the range of 8:1. Sustained U.S. investment and innovation will be required to preserve past productivity gains in the face of climate change, coevolving pests and diseases, and changing technological regulations—let alone increase productivity. Great potential exists for innovation in crop and livestock genetics and digital farming technologies to generate new products and production processes, but innovators have to overcome increasingly strong headwinds from social and political forces that seek to dictate technology choices.

Endnotes

¹The year 2007 is the latest year in our consistent series of data on input, output, and productivity.

²More complete descriptions of the ideas and information summarized in this paper can be found in Alston and Pardey (2020), Pardey and others (2016a, 2016b), and Pardey and Alston (forthcoming).

³As Pardey and Alston (forthcoming) show, national MFP growth is equal to the sector-input-share weighted average of farm and nonfarm MFP growth.

⁴Pardey and Alston (forthcoming) confirm these informal impressions by fitting a cubic polynomial trend model in logarithms to each of the MFP data series summarized in Table 1 for the period 1910–2007. In each case, the model fits the data fairly well (R^2 values of at least 0.98), and we can strongly reject the nested special case of a linear model with a constant exponential growth rate against the alternative of a cubic model that implies a surge and a slowdown.

⁵Throughout this paper, unless we state otherwise, “agricultural R&D” refers to the aggregate of R&D related to food and agriculture.

⁶Sumner, Alston, and Glauber (2010) provide a concise review and cite several notable economists who have written on the issue, including Houthakker (1967, p. 5) who wrote, “The Farm Problem, it will be argued here, is primarily a problem of economic growth. To put it briefly: ... economic growth requires a steady shift of labor and other resources from agriculture to other sectors. Since there is resistance to this shift, there are usually too many people in farming and as a result per capita farm income is depressed.” See also Gardner (1992, 2002).

⁷Many expect the variation in climate (or pest and disease) pressures to pick up pace and increase in the decades ahead, implying an increase in demand for maintenance research.

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