The Role of Private-Sector R&D in Agricultural Innovation: Improving Yields, Equipment Productivity, and Sustainability

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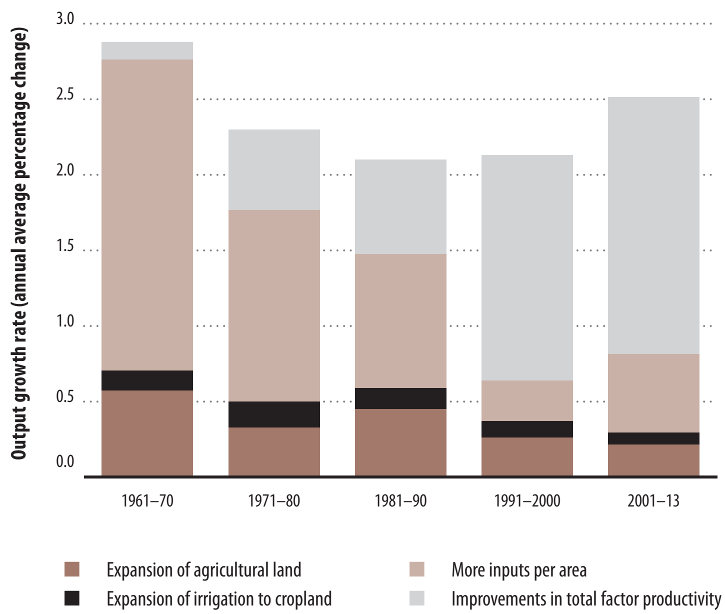
By 2050, according to the United Nations, the world's population is estimated to reach 9.7 billion.[1] This presents the global agriculture sector with a daunting challenge, especially when combined with the effects of climate change and resource scarcity. The stage has been set for a potential global food crisis if policy makers and other stakeholders fail to act: Ensuring adequate supplies of food will require a 70% increase in agricultural production over the next 30 years.[2]

The pace of agricultural innovation has increased over the last 10 to 15 years, with advances in genomics, software, communications, logistics, and technology. The public sector has traditionally been the driving force behind these advances and represented the lion's share of agricultural research and development (R&D) expenditures, with global public-sector R&D accounting for 55% of the US$69 billion total in 2011 (the most recent year for which global data are available).[3] But more recently, constrained fiscal policies in many countries have slowed public-sector R&D growth. The private sector has increasingly filled the gap: Private investment in agricultural innovation has resulted in new technologies and production techniques with significant promise to boost productivity.

Figure 1: Sources of growth in global agricultural output, 1961–2013



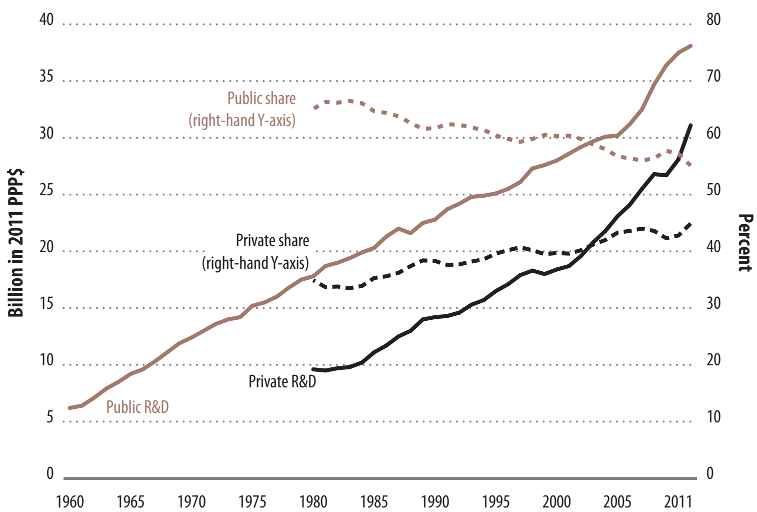
Source: USDA Economic Research Service, 2017.

Output and productivity

Before 1970, the expansion of land under cultivation and other inputs—such as labour and capital per acre—accounted for the vast majority of the growth in global agricultural output. Since 1990, however, the rate of growth in land, labour, capital, and other material inputs has dramatically slowed, and increasing total factor productivity (TFP)—which measures the efficiency with which all agricultural inputs are transformed into outputs—has become the main driver of agricultural productivity growth. From 2001 to 2013, TFP accounted for more than two-thirds of the overall growth in output (see Figure 1).[4]

However, the 2016 *Global Agricultural Productivity Report,* a benchmark that analyses agricultural productivity growth (compiled by the private-sector group Global Harvest

Figure 2: Public and private agricultural R&D



Source: Pardey et al. (University of Minnesota, InSTePP International Innovation Accounts, 2016).

Initiative), has found that global TFP is not growing fast enough to meet projected population-driven increases in food demand by 2050. This inadequate growth is mostly the result of lagging TFP growth in low-income countries, where the current average growth rate is 25% lower than the global average.[5] In these countries, the bulk of output growth still comes from increasing agricultural inputs and land under cultivation—creating even greater need for productivity gains.

Driving further growth in TFP rates demands greater investment in agricultural R&D. Unfortunately, the growth of public-sector investment has slowed in many high-income countries, including those of Western Europe, and has declined sharply in the United States of America (USA) in recent years (falling more than 20% in real terms from 2008 to 2013). R&D spending in low-income countries is also lagging, particularly when measured on a per capita basis. In 2011, high-income countries spent US$17.73 per person, compared to US$1.51 in low-income countries.[6]

At the same time, public-sector spending has been increasing in middle-income countries, including Brazil, India, and especially China; the last-mentioned has accounted for a majority of the net growth in global public-sector agricultural R&D in recent years. From 2008 to 2013, China increased its spending nearly 70%.[7]

Private-sector R&D spending, meanwhile, has been growing robustly in recent years, especially in high-income countries (see Figure 2).[8] In the USA, private- and public-sector spending were roughly equal in the 1980s and 1990s; in 2000, for example, each sector contributed 50%. But by 2013, the public share had declined and private investment had risen; the private sector now accounts for 75% of total US R&D.

Such growth can be traced to advances in genetic engineering in the mid-1980s, which gave rise to a wave of technological innovation that boosted returns on private investment, and to the increasing marketization of the agricultural supply chain in many regions. Over the past 10 years, investment in agricultural innovation has been fuelled by an unprecedented convergence of advances in biology, agronomy, plant and animal science, digitization, and robotics. These technologies—often referred to collectively as 'digital agriculture',[9] precision farming', or 'smart farming'—are creating the foundation for a new, more productive and sustainable future of agriculture. Farm ownership patterns are also changing, creating a multiplier effect because farmers who automate are able to manage larger fields and greater numbers of animals.

Much of this new wave of innovation is enabled by the shift in corporate R&D towards software, advanced hardware, and service offerings. The integration of embedded software and sensors in farm equipment, in the soil, and on the animals—as well as the ability to reliably and inexpensively connect and network agricultural producers, suppliers, products, and customers using cloud-based systems and shared analytics—has significant potential to increase output.[10] Such innovations are enabling major gains in yields, asset productivity, and sustainability that will be key factors in meeting the escalating demand for food (see Figure 3).

Increasing yields

The development and widespread adoption of hybrid seeds led to the most significant improvements in crop yields in the 20th century. For example, the adoption of hybrid corn (maize) in the USA—aided by improvements in tillage practices, herbicides, and equipment—increased yields by a factor of five from the 1940s to the present.[11] In the 1990s, genetically modified crops (GMCs) launched a new wave of major yield improvements; today more than 90% of the planted area of soybeans, cotton, and corn in the USA are genetically modified varieties. These hybrids are also in wide use in South America and Asia—most notably in China and in India. Adoption of GMCs has been controversial, however, and health fears have limited their penetration in Europe.[12]

The latest advances in genomics promise to increase crop yields while avoiding some of the features that have caused concern about GMCs. A technology under development known as CRISPR (which stands for 'clustered regularly interspaced short palindromic repeats') for example, which is now being adapted for crop and animal science, uses the immune system of bacteria to edit specific genes in organisms. Unlike processes used for traditional GMCs, CRISPR does not introduce genes from other organisms into plants but instead edits the genome of the plant itself. Scientists believe the CRISPR outcomes could improve the natural characteristics of crops to make them more resistant to drought, pests, and weeds, and could boost their photosynthetic efficiency to make them grow faster. Companies are already developing applications of the technology to improve drought resistance for crops and to improve livestock resistance to diseases, such as African swine fever.[13]

R&D in sensor technology, geo-positioning, and big data will also enable significant increases in crop and livestock yields. The Climate Corporation, a subsidiary of Monsanto, launched its Climate FieldView platform in 2015. This platform, backed by a powerful data science engine and an extensive field research network, uses sensors and satellite imagery to provide farmers with real-time data to maximize crop yields. It enables precision application of fertilizers and can also identify and prevent disease vulnerability. FieldView is already in operation on more than 100 million acres in the USA and Brazil. The Climate Corporation has recently expanded into the European market, and plans to also offer the platform in South Africa, Australia, and Argentina over the next few years.[14] More and more big-data solutions of this nature are expected both from start-ups and from legacy agribusiness organizations that serve growers around the world.

Another example of the implementation of new technology is happening at My Dairy Dashboard, a joint venture of Virtus Nutrition and Dairy.com in the USA, announced in May 2017. Virtus had previously acquired Farmeron, a Croatian startup that developed a cloud-based software platform for data management and agricultural production performance optimized for dairy farmers. My Dairy Dashboard will provide data aggregation for the dairy farm industry, to help enhance production and streamline operations.[15]

Innovations in drone technology will also enable increases in yields. Companies are adapting drones to produce precise three-dimensional maps for soil analysis and to optimize irrigation and nitrogen-level management. Start-ups are developing drone systems for planting that shoot pods with seeds and nutrients into the soil. Drones are also being developed to spray crops far more precisely and efficiently than current tractor-based technologies. Drones with thermal sensors are well suited for monitoring crop health and growth.[16]

Some African countries are pursuing R&D in aquaculture to develop inland fish farming as a potentially large future source of protein. In the United Republic of Tanzania, the National Aquaculture Development Centre is working with a consortium of local and global educational and nonprofit organizations to identify and optimize the best species of native tilapia for farming, and to adopt best practices from aquaculture experience around

Figure 3: Three imperatives driving future investments across agribusiness markets

INCREASING YIELDS	IMPROVING ASSET PRODUCTIVITY	ENHANCING SUSTAINABILITY
Precision agriculture solutions	Enterprise resource planning (ERP) systems for the farm	Land use mapping
Integrated equipment	Telematics	Managing water
Data collection and data entry	Autonomous equipment	Energy management
Image management	Drones	Waste tracking
Consultative support	Sensory networks	Input traceability
Access to season trends and facts	Services enablement	Farm/field performance reporting
	Predictive analytics	Harvest tractability

Source: PwC, 2016b.
Note: Farmers who deliver profitability across all three objectives will likely expand their acreage and become enterprise agribusiness leaders in their markets.

the world. The Tanzanian government aims to triple the contribution of aquaculture to the nation's GDP from its current 1.4% to 4.2% by 2025.[17]

Not all promising innovations for raising yields rely on cutting-edge science; some leverage older technologies. AgroStar, a start-up based in Pune, India, has developed a mobile-commerce platform that helps small farmers access raw materials, seed, fertilizer, and other agricultural inputs in rural areas that are often plagued by product unavailability, unfair prices, substandard quality, and limited information. AgroStar enables its customers to order using a mobile app or via the 'missed call' technique (dialling a number and disconnecting before the call is picked up, thus signalling the recipient that the caller wants to order or communicate while avoiding cell-phone usage charges). The company, which launched in 2012, has partnered with more than 150 brands, including multinationals such as Syngenta, and has served 7 million farmers in the states of Maharashtra, Gujarat, and Rajasthan.[18]

Improving asset productivity

One of the most notable innovations in improving asset productivity was the invention of the cotton gin in 1793. The new machine could process 1,000 pounds of cotton in the time it took an individual to process five pounds by hand.[19] Over the past decade, major agricultural equipment manufacturers have been attempting another dramatic transformation by building increasingly sophisticated digital features into farm equipment to boost productivity.

The latest models of tractors, planters, harvesters, and other equipment from companies such as Case IH, John Deere, and Kubota feature monitors, sensors, and software that optimize farming processes and generate detailed computerized data—enabling farmers to maximize their productivity and increase their yields while gaining a wealth of information to help them manage their operations more efficiently. Manufacturers have also been developing sophisticated autonomous tractors and other vehicles over the last several years, and have prototypes in operation today.

Case IH, for example, unveiled an autonomous tractor concept in 2016—the Case IH Autonomous Concept Vehicle—built with a fully interactive interface that allows remote monitoring of pre-programmed operations. These include automatically accounting for implement widths, and plotting the most efficient paths in a field depending on terrain, obstructions, and other machines in use in the same field. A remote operator can monitor and control the tractor from a computer or tablet. Such vehicles can operate around the clock, and can provide the farmer with predictive information on maintenance.[20]

Equipment manufacturers and third-party vendors are also offering software and Global Positioning System (GPS) packages that can track and map an agricultural producer's mechanized equipment. This enables farmers to monitor their machines on a tablet or smart phone and direct them to where they are needed—when, for example, a storm is coming—and to re-route support vehicles carrying fuel, seed, and fertilizer. Similar tracking and mapping software is also available for livestock. Collars or tags placed on the animals can send real-time data to farmers and ranchers not only on livestock location, but also on weather conditions, health, and mating patterns.[21]

Finally, companies are developing innovative technologies for offshore aquaculture operations that can grow and harvest different varieties of seafood in oceans, including smart floating farms and submersible cages that can be located near cities or out at sea.[22] Ocean Farming, for example, a subsidiary of the Norwegian fish farming company SalMar, is adapting deep-water petroleum technology to develop offshore salmon farms that would anchor 100-metre steel cages that float below the surface to the ocean floor and adapt to the motion of waves and currents. The company estimates these could be eight times as productive as traditional inshore fish farms.[23]

Enhancing sustainability

The introduction of sustainable techniques such as contour farming—the practice of planting crops in rows running parallel, rather than perpendicular, to the contours of the land—reduced topsoil loss by 65% within five years during the environmental and humanitarian crisis known as the Dust Bowl in the USA during the 1930s.[24] In recent decades, many key innovations in sustainability have focused on more efficient irrigation techniques. In most parts of the world where irrigation is necessary, variations of field flooding—the least efficient method—are still used. More efficient methods, such as central pivot systems, which use wheeled booms to apply water to crops more precisely, have been in use in high-income countries since the 1950s.

T-L Irrigation, a leading producer of centre wheel systems, introduced a new system for arid farming areas in 2014 that combines the central pivot and drip irrigation approaches. Drip hoses, spaced a few feet apart, apply water directly to crops, minimizing evaporation, and can reach water efficiency levels of 95%.[25] By adding sensors to these types of irrigation equipment to optimize water application, water use could be reduced by as much as 50% and yields could be increased by 10% or more.[26]

Access to fresh water is another focus of sustainability efforts, especially in arid climates.

In 2012, the World Bank reported that 14 of the 20 most water-scarce countries in the world were located in the Middle East and North Africa (MENA) region.[27] Desalination currently plays a critical role in supplying water to the populations of MENA countries, and will continue to do so moving forward as these populations continue to grow. But desalination plants are energy and resource intensive, and for that reason many MENA countries are investing in concentrating solar power (CSP) plants, which use large mirrors to generate thermal energy for desalination. Given the high costs associated with CSP, the public and private sectors will need to work together to ensure broader adoption.[28]

In addition to improving sustainability, players across the agricultural supply chain are also keenly interested in creating transparency and trust about their sustainability efforts. For example, major food companies and retailers are making public sustainability commitments to improve their environmental footprints. Land O'Lakes, a farmer-owned cooperative with more than 4,300 members based in Minnesota, USA, created a new business unit named SUSTAIN to align its environmental sustainability efforts across its enterprise, which operates in all 50 US states and more than 50 other countries.[29] The SUSTAIN programme focuses on sustainable crop production by delivering products, services, and insights; enhancing sustainability within the dairy foods and feed businesses; and partnering with other entities, including governments, to improve efficiency and collaboration on water conservation and sustainability. The programme also offers tracking, reporting, and aggregated results that enable farmers to communicate their sustainability results to their customers and retailers to document and communicate the sustainability of their products to end consumers.

The R&D challenges in agriculture

The imperative to raise the productivity of agricultural R&D by up to 70% over the next three decades will require the public and private sector to address several critical challenges.

Speeding R&D cycles and furthering the widespread adoption of promising innovations—particularly in low-income countries—are a precursor to improving outputs. The lags between successful R&D efforts and the widespread adoption of agricultural innovations tend to be long; at least 15 to 25 years before peak impacts, with further adoption lags that can continue for decades. In the USA, for example, the earliest research on hybrid corn technology began as early as the 1890s, and focused research did not begin until 1918. Commercial adoption, however, began only in the 1930s and was uneven. And not until 1960 was almost all US corn acreage in hybrids. Thus the total adoption cycle took over 40 years—or arguably longer.[30]

Another challenge is that many of the most promising agricultural innovations are capital-intensive, and agriculture has historically been dominated by small businesses with low profitability and limited access to capital. Several trends offer promise in overcoming such obstacles, however. For one, consolidation in agriculture will boost efficiency, with fewer farmers and ranchers managing larger fields. In addition, more widespread use of crop insurance is an example of a financial innovation that could provide farmers and ranchers with more financial security. Agricultural insurance lowers risks as well as improving access to credit. At present, in higher-income counties, 1.99% of agricultural GDP is spent on agricultural insurance, but that falls to 0.29% in upper-middle-income countries, 0.16% in lower-middle-income countries, and 0.01% in low-income countries.[31]

Some scientists and researchers also note that economic and environmental changes, such as changes in weather patterns and crop pests and diseases, could undermine past patterns of productivity growth. This is a particular concern in low-income countries, where the demand for food is growing the fastest. Low levels of public-sector R&D investment, which is best suited to creating solutions to these kinds of problems, could slow productivity improvements and put these countries at risk.

Conclusions: Feeding the World

The public sector needs to reverse the negative trend in R&D spending growth in many high-income countries, and increase R&D spending in low-income countries—making investments in basic scientific research in agriculture and supporting technologies. But governments can also foster an attractive environment for venture capital funds and corporate ventures focusing on agricultural innovation, and help ensure that the investments being made by the private sector can make a greater impact, by taking the following steps:

- Support agricultural extension efforts to disseminate knowledge about new technologies and techniques and to demonstrate their business case. Publicly funded agricultural extension has been a key historical link between agricultural R&D and farmers and ranchers in high-income countries. Governments and supra-national organizations should prioritize implementing such programmes in low-income countries.
- Streamline regulation to reduce lag times, provide targeted tax relief to enhance farmers' incomes and financial security, and offer preferential access to land and market support for promising agricultural techniques and technologies.
- Create public-private partnerships, which governments can use to leverage public-sector investment, enhance private-sector involvement in agriculture infrastructure, and fill gaps in the delivery and adoption of innovation by public- and private-sector entities acting independently.[32]
- Maintain and expand regional and international trade in agriculture outputs. Many of the gains in productivity in recent decades have been enabled by globalization and the rise of extended agricultural value chains.

The rise of commercial R&D in agriculture underway today—and the resulting innovations in improving yields, asset productivity, and sustainability—provide the means for meeting the food needs of the world's growing population by 2050. But to reach that goal, both the public and private sectors will need to keep the R&D pipeline flowing and make investments and commitments to ensure that innovative technologies and techniques are widely and rapidly adopted by countries across the income spectrum.

Notes

1 See http://www.un.org/en/development/desa/news/population/2015-report.html for more on population growth estimates.

2 PwC, 2015.

3 Pardey et al., 2016a.

4 USDA Economic Research Service, 2017

5 Global Harvest Initiative, 2016.

6 Pardey et al., 2016b.

7 Pardey et al., 2016b.

8 Pardey et al., 2016a.

9 See Chapter 4 of this report.

10 Jaruzelski et al., 2016.

11 Russell and Sandall, 2017.

12 See http://www.isaaa.org/resources/publications/pocketk/16/ for more information on biotech crop adaptation.

13 Montenegro, 2016.

14 See https://climate.com/?gclid=CKvDi5qVtNECFZWLswodSusK_A for more information on The Climate Corporation's FieldView platform.

15 See http://mydairydashboard.com/index.html for more on the joint venture between Virtus Nutrition and Dairy.com.

16 PwC, 2016a.

17 Earlham Institute, 2017.

18 ET Bureau, 2016.

19 See https://www.eliwhitney.org/7/museum/eli-whitney/cotton-gin and http://www.farmcollector.com/equipment/ten-agricultural-inventions-in-farming-history for more on the invention of the cotton gin.

20 See https://www.caseih.com/northamerica/en-us/Pages/campaigns/autonomous-concept-vehicle.aspx for more on the Case IH autonomous concept vehicle.

21 See https://www.theintelligenceofthings.com/article/connected-farm-big-data-agriculture/ for more on connected farm solutions.

22 Kearnes, 2016.

23 Nortrade, 2015.

24 The Nature Conservancy, No date.

25 See http://tlirr.com/products/precision_mobile_drip_irrigation/ for information about T-L Precision Mobile Drip Irrigation.

26 Goldman Sachs, 2016.

27 The convention in the GII is to refer to UN regions. In this chapter, the 'Middle East and North Africa (MENA) region' refers to the region as defined by the World Bank; for a list of these countries, see http://www.worldbank.org/en/region/mena.

28 World Bank, 2012.

29 See https://www.landolakesinc.com/Blog/December-2016/Land-O-Lakes-SUSTAIN-gears-up for more on Land O'Lakes' SUSTAIN programme.

30 Pardey and Alston, 2010.

31 Villalobos, 2013.

32 Moreddu, 2016.

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