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Public agricultural R&D in high-income countries: Old and new roles in a new funding environment

Paul W. Heisey*, Keith O. Fuglie

Economic Research Service, US Department of Agriculture, 355E Street SW, Room 6-262, Washington, DC 20024-3221, USA

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ABSTRACT

In recent years, public agricultural R&D investment in high-income countries has grown considerably more slowly than public agricultural R&D in developing countries, private R&D for agricultural inputs, or private food R&D. Funding trends in these countries have resulted in part from structural changes in the economy, changes in general agricultural policy, and an expanded research agenda. Shifts in agricultural research policy have had a mixed record of success in meeting objectives and have had limited impact in expanding the real resources devoted to agricultural research. However, public agricultural R&D in these countries continues to produce high quality scientific output and measurable impacts on productivity. These research systems continue to be an integral part of the global agricultural research effort.

1. Introduction

Commitment of public resources to agricultural research[1] in today's high-income countries has been a major contributor to technological and structural change in agriculture. For high-income countries in the aggregate, virtually all growth in agricultural output is now due to improvements in productivity—measured as changes in the ratio of aggregate outputs to aggregate inputs, or total factor productivity (TFP). In turn, investments in public and private agricultural research and development (R&D) have been the most notable factors contributing to agricultural TFP growth (Fuglie, 2018). The world as a whole is also becoming more dependent on productivity to raise agricultural production. Since 1990 about three-quarters of the growth in global agricultural output has come from increasing TFP and only about one-fourth from expanding the use of inputs in production (Fig. 1).

Many of the origins of modern agricultural science trace to 19th century Europe, in particular the foundations of organic chemistry and genetics. Institutions such as the research university and the agricultural experiment station also trace their origins to Europe (Ruttan, 1982; Alston et al., 1998). The U.S. model of integrated agricultural research and education, frequently analyzed and sometimes emulated, also dates to the second half of the 19th century (Huffman and Evenson, 2006). In the United States, only defense and public health rivalled agriculture for early government support of research (Hounshell, 1984; Terris, 1992). As late as 1940, almost 40% of U.S. Federal expenditures for R&D went to agriculture (Mowery and Rosenberg, 1989).

Nonetheless, both the geographic locus and institutional configuration of global agricultural research have shifted significantly in recent years, with widely noted increases in public agricultural R&D in some developing countries and in private agricultural and food R&D, while public agricultural R&D in high-income countries has grown more slowly (Beintema et al., 2012; Pardey et al., 2016; Fuglie, 2016). Between 1990 and 2011, public agricultural research expenditures by high-income countries fell from a 36% to 24% share of the global total investment in agricultural and food research. Over the same period, public R&D by other countries and private food manufacturing research more than doubled; private R&D by agricultural input companies also nearly doubled (Fig. 2).

In this review, we examine the changing roles of public agricultural R&D in high-income countries. We begin by outlining the position of these countries in the global food system and their role in the global agricultural research system, as well as some of the impacts of public

* Corresponding author.
E-mail address: pheisey@ers.usda.gov (P.W. Heisey).

[1] In the later analysis, "public agricultural research" expenditures are defined, following convention, as the sum of agricultural research expenditures by government research institutes, higher education institutions, and, in some cases, private non-profit organizations. In cases in the modern era for which data are available, roughly 80–90% of the resources for these expenditures appear to come from governmental sources, with the rest made up of components such as contract research, product sales, licensing royalties, grants from private institutions, and so on.

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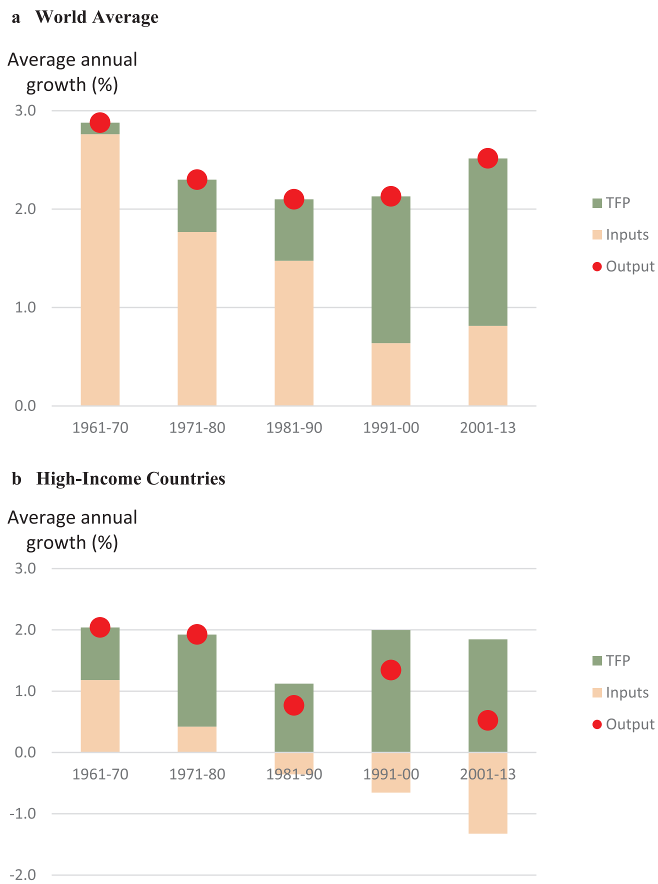

Fig. 1. Contributions of inputs and Total Factor Productivity (TFP) to agricultural growth. Total factor productivity (TFP) growth is estimated as the difference between real output growth and real input growth. Agricultural output growth is based on the Food and Agricultural Organisation of the United Nations (FAO) Gross Agricultural Output measure, an aggregation of about 190 crop and livestock commodities based on a fixed set of average world farm-level commodity prices from the 2004–2006 period. Real input growth is the weighted-average growth rate of agricultural labor, quality-adjusted agricultural land, agricultural capital, and fertilizer and feed variable inputs, where the weights are average cost shares. This figure updates estimates from Fuglie (2015), which provides further details on methodology.

agricultural research. We then take a closer look at trends in high-income country public agricultural R&D, uncovering a number of empirical regularities that suggest structural patterns in public research funding. After that, we consider the ways agricultural research policy is conditioned by larger agricultural sector policies, and summarize the developments of changes in agricultural research policy that have resulted from changes in farm structure, the rise of corporate agriculture in providing new technologies and services to the farm sector, and changing consumer expectations of the role of agriculture in both the food system and the natural environment. The review concludes with a summary of key findings and a discussion of their implications for agricultural science policy.

2. High-income countries in the world food, agricultural, and research systems

2.1. Agricultural production and trade

Most of the data in this review refer to 31 high-income members of the Organisation for Economic Co-operation and Development (OECD).[2] In 2014, these countries comprised about 14% of the global population, but produced approximately 24% of global agricultural output.

Although these countries produce a greater share of world agricultural output than their population share, they are also larger consumers of agricultural products, and include a number of large net importers, such as Japan, the UK, South Korea, and Germany. Nonetheless, this group of high-income countries also includes the world's largest agricultural exporter, the United States (and third largest net exporter in recent years). Furthermore, of the world's top fifteen net agricultural exporters between 2009 and 2013, eight—the U.S., Netherlands, Australia, France, New Zealand, Canada, Spain, and Denmark—are high-income countries. Beckman et al. (2017) show that the share of total agricultural exports accounted for by developed countries fell from 63% to 54% between 1995 and 2012–14, while the developed countries' share of total agricultural imports also fell from 72% to 58%. The main increases in agricultural trade over these years have been accounted for by Brazil, Indonesia, and India (net exporters) and the Russian Federation and China (net importers).

2.2. Upstream global agricultural science capacity

Despite the declining share of global food and agricultural R&D accounted for by the public sectors of high-income countries, they continue to account for a much of the intermediate output in agricultural and related sciences, producing an outsized share of global agricultural research capital. In this section we compare university rankings, numbers of agricultural science Ph.Ds granted, and scientific publications. An important additional indicator for which we do not presently have more complete data would be for human capital employed in agricultural research, represented at first approximation by counts of agricultural scientists.

In upstream biological sciences, 47 of the top-ranked 50 universities in the 2017 QS World University Rankings were located in the countries in this review. Forty-five of the top 50 universities in agriculture and forestry were in high-income OECD countries (Table 1).

Grants of agricultural sciences Ph.Ds in high-income countries rose modestly between 2000 and 2014. For developing countries, data are not available in most cases, but awarded agricultural science Ph.Ds increased dramatically in two large developing countries, by two-thirds in India and by fivefold in China (Table 1). For most countries it is not possible to determine how many Ph.D.s were granted to non-citizens, nor their eventual employment locations. However in the U.S., roughly 45% of recent Ph.D.s in agricultural and environmental sciences were granted to non-citizens in recent years (National Science Foundation, 2018), and in Australia, about 25% of agricultural sciences Ph.D.s were granted to non-citizens (Dobson, 2012a), an indicator of how these

[2] The OECD is a Paris-based intergovernmental organisation that currently comprises 35 countries. It is a successor to the Organisation for European Economic Cooperation, founded to administer the Marshall Plan in Europe. Membership has tended to indicate some degree of "responsibility" in economic policy. "High-income" status is based on the World Bank Classification. The 31 countries covered are:

- North America: Canada and the United States;
- Asia: Japan and South Korea;
- Oceania: Australia and New Zealand;
- Northwest Europe: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Iceland, Luxembourg (sometimes combined with Belgium), Netherlands, Norway, Sweden, Switzerland, and the United Kingdom;
- Southern Europe and the Mediterranean: Greece, Israel, Italy, Portugal, and Spain;
- Central Europe: the Czech Republic, Estonia, Hungary, Poland, Slovakia, and Slovenia.

Two high-income OECD member countries are not covered (Chile, which attained high-income status in 2012, not included because of its unique location in South America, and Latvia which only joined the OECD in 2016). Two other OECD members (Turkey and Mexico) are classified as upper-middle-income countries. One high-income country with notable public agricultural research expenditure, Taiwan, is not an OECD member and is also not included in the more detailed data.