Chapter 17

AGRICULTURAL INNOVATION POLICIES
Prioritizing Investments and Promoting Uptake and Impacts at Scale

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Key messages

- Innovation in agriculture—including in technological innovation in crop varieties, livestock breeds, and agricultural practices, as well as changes in organizations, policies, and rules—offers a solution to many pressing development problems in low- and middle-income countries, particularly low productivity and poverty.
- Research on the economics of agricultural R&D examined its costs and benefits, demonstrating high returns in terms of productivity and poverty reduction. To support priority-setting and policymaking by governments and funders, researchers developed a set of widely used analytic tool kits for resource allocation and prioritization, including spatial analysis and econometric and computational models, as well as data sets on agricultural investment and capacity.
- Researchers adopted a systems perspective to understand the various actors and social, economic, and political institutions involved in complex innovation processes. The agricultural innovation systems concept pointed to the need for organizational innovation to coordinate diverse actors around efforts to solve complex problems in food systems, and led to the development of various types of multistakeholder innovation platforms and partnerships.
- Recently, innovations research has focused on barriers and enabling policies for scaling promising innovations. Effective scaling is often facilitated by "socio-technical innovation bundles" of policy change, technology options, delivery methods, market links, and coordination mechanisms.

Two successful IFPRI programs—on biofortification and biosafety—offer lessons for a holistic and integrated approach to scaling.

Looking to the future, the review of innovation research points to three key agendas:

- **Develop new methods and integrated frameworks** to better assess multiple policy objectives and inform resource allocation in the context of competing development goals, such as increasing production and addressing climate change. This effort will require systematic integration of spatial analysis, farm models, simulation, and sector and economy-wide models, among other advances.
- **Inform scaling efforts through a better understanding of how to develop best-fit approaches** that consider the local context when scaling innovations for agronomy and natural resource management. Collaborations between research and development organizations on large-scale projects could build evidence on how to create enabling conditions for uptake of innovations.
- **Conduct rigorous impact evaluations**, along with action plans for scalability, of different technological, organizational, and institutional innovations, as well as in-depth analysis of the political economy, policy actions, and enabling environments that support innovations and scale their impacts. It is crucial to focus on which innovative solutions have been shown to be beneficial and how to bring them to diverse farmers' fields.

From the advent of the first farming tools to modern innovations in molecular biology and genetics, technological progress in agriculture has played a critical role in human history and will continue to be essential in tackling the multiplying challenges facing food systems. However, technical change—and accompanying gains in productivity and welfare—has been unevenly distributed across the globe, with some countries and communities benefiting far more than others (Fuglie and Rada 2016; Fuglie et al. 2019; He and Li 2020; Walker et al. 2015).

Given that agricultural science, technology, and innovation are an important solution to the many pressing development challenges facing low- and middle-income countries (LMICs), more attention needs to be directed to this uneven pace of change. Public policy can play a role in shaping social, economic, and individual choices about technical change, and technical change itself is acutely dependent on changes in the social and economic policy

environment in which individuals make choices. This chapter reviews the evolution of research on technical change and public policy, from the seminal economic analyses that highlighted the importance of technical change, to innovation systems analyses that broadened our understanding of the technical change process, on to the latest strategies for accelerating change.

To better manage this broad topic, we examine three distinct but overlapping policy agendas on technical change: (1) the agricultural R&D and productivity growth–poverty reduction agenda, (2) the agricultural innovation systems agenda, and (3) the impact-scaling agenda. Within these agendas, we consider three broad types of innovation that reflect long-standing areas of scientific research and innovation. First is biological innovation, or improvements to the genotypic and phenotypic characteristics of cultivated crop varieties and livestock breeds. Second is agronomic innovation, or improvements in the principles and practices applied to the management of agricultural, natural resource, and ecological systems. Third is institutional innovation, or changes in the policies, rules, and norms shared and adhered to by a society, country, or community.[1]

Focusing on the uneven pace of change in LMICs also requires understanding the root causes of the problem: Can it be explained simply by the many competing R&D priorities vying for limited financial and scientific resources? Does the difficulty lie in moving from fundamental research to practical use—that is, from pure basic research to use-inspired basic research to pure applied research? Or is the problem rooted in institutional factors (shared norms, beliefs, and rules in society) or behavioral factors (individual preferences, expectations, and cognitive biases) that shape our willingness to experiment, adopt, and benefit from technical change?

The economics of agricultural R&D and the productivity growth–poverty reduction agenda

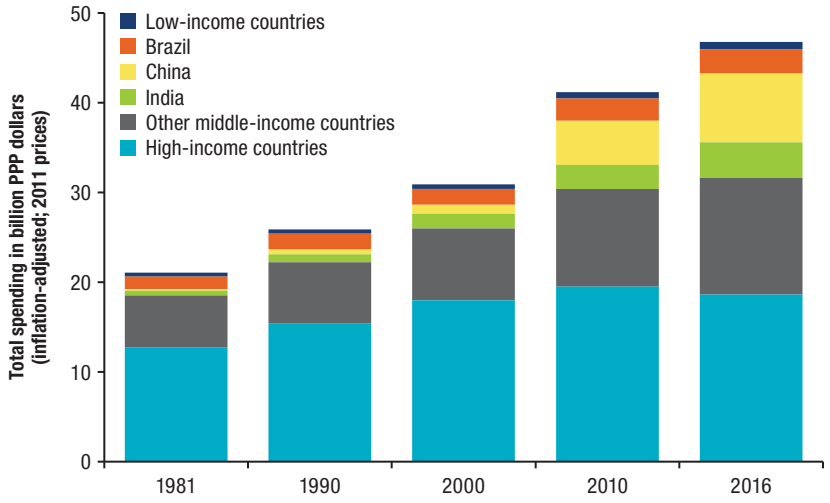
Beginning with seminal work in the 1960s and 1970s (Griliches 1964; Hayami and Ruttan 1971), research on agricultural innovation policy has focused on how to produce food, given relative scarcities in the factors of production—land, labor, and capital—and how R&D can increase production and productivity. This focus gave rise to a rich body of research on the benefits and costs

1 We purposely limit this chapter to farm-level innovations; equally important off-farm innovations are discussed in Chapter 7 on food value chains and Chapter 12 on nutrition programs. This chapter focuses on high-level investments, policies, and institutions; equally important discussions on last-mile delivery services and farmers' adoption are found in Chapters 8–10.

of agricultural R&D investments, the rates of return on these investments, and the resulting R&D priorities needed to accelerate agricultural development, food security, and economic growth (Alston et al. 1995, 2000). Early research in this area helped to justify the resources needed for the world's first multilateral program to address a global development challenge—hunger and food insecurity—and thus led to the formation of the Consultative Group on International Agricultural Research, now known as CGIAR (see Box 17.1).

Beginning in the mid-1980s, studies conducted over the next two decades broadly demonstrated high social returns to agricultural R&D in both productivity growth (Alston et al. 2000) and poverty reduction (Fan and Hazell 2001). These findings were based on a wide range of more context-specific studies on the Green Revolution (Hazell and Ramaswamy 1991), natural resource management (Pender 2005), and new varieties, agronomic practices, and other technological advances (Pingali 2022). This work demonstrated the continued importance of public expenditure on the production of public goods for food and agriculture, despite persistently low and volatile public spending by LMICs (Figures 17.1 and 17.2). Unfortunately, this scholarship and evidence did not prevent a precipitous decline in funding for agricultural R&D, which began during the same period due to donor fatigue and declines in national budgets and official development assistance (see Chapter 18) (Byerlee et al. 2002).

FIGURE 17.1 Agricultural research spending by income group, 1981–2016



Source: Beintema, Nin-Pratt, and Stads (2020).

BOX 17.1 Mission and structure of CGIAR

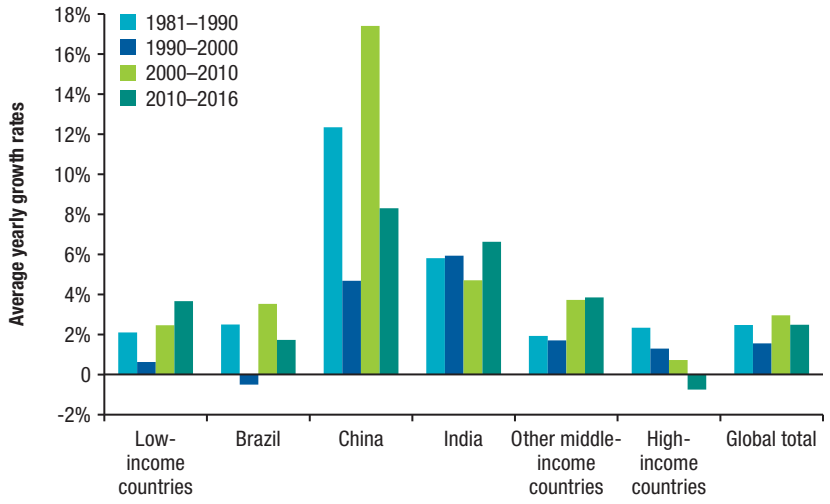
CGIAR, known as the Consultative Group on International Agricultural Research when it was created in 1971, is a funding and coordination mechanism for a diverse system of 15 international agricultural research centers (IARCs) focusing largely on the tropics and subtropics. Six IARCs were established before CGIAR's founding, beginning with the International Rice Research Institute in Los Baños, the Philippines, in 1960. Because the first IARCs were closely associated with the Green Revolution that emerged in the late 1960s, these centers were arguably the 20th century's major institutional innovation for foreign assistance to support agricultural development and food security.

In its current structure, CGIAR's mission is to deliver science and innovation that advance the transformation of food, land, and water systems in a climate crisis. The IARC model that emerged in the 1960s, and still largely holds, had four core characteristics. First, IARCs were set up as "centers of excellence" to carry out multidisciplinary research that would generate technology and knowledge spillovers across countries and aimed to create efficiencies through economies of scale and scope. Second, in the medium term, they aimed to compensate for weaknesses in many developing country national research systems while, over the long term, strengthening the capacity of those systems through in-service training and graduate training, often linked to a nearby university. Third, they aimed to reduce political and bureaucratic interference in science by operating as autonomous nongovernmental entities with their own independent but internationally representative boards.

Finally, IARCs were to receive long-term funding from multiple sources, largely from richer countries through their official foreign assistance and philanthropic organizations, complemented by contributions from low- and middle-income and host governments. Agricultural research that would benefit many countries was seen to be a meaningful way for these donor organizations to realize their humanitarian and political objectives. Reflecting the increased understanding of the importance of policies in fostering and scaling innovations, IFPRI was established as one of the IARCs and joined CGIAR in 1979. The IARCs inherited a proven model of crop research but have struggled with a model for natural resources management, as well as stable funding.

Source: Byerlee and Lynam (2020).

FIGURE 17.2 Growth in agricultural research spending by income group, 1981–2016



Source: Beintema, Nin-Pratt, and Stads (2020).

Nevertheless, this body of work helped build a set of analytical tool-kits on R&D resource allocation that LMIC researchers still rely on today. The first external program review of IFPRI in 1985 acknowledged that the "allocation of research resources is an elusive problem for which the methodology has not yet been established" (CGIAR TAC 1985, 7). With the publication of *Science under Scarcity* in 1995, IFPRI, together with Julian Alston and George Norton, produced the standard methodological reference on agricultural research evaluation, priority setting, and resource allocation (Alston et al. 1995).

Spatial analysis became a principal tool as the focus of agricultural research shifted from irrigated systems, which were central to the early Green Revolution, to the extensive rainfed farming systems across the developing world. Spatial analysis addressed the need to integrate the diversity and heterogeneity of these farming systems into research priority-setting in response to urgent global sustainability objectives. A good example comes from the International Maize and Wheat Improvement Center (CIMMYT), which in the late 1980s used spatial analysis to defined "mega-environments" (Hartkamp et al. 2000) intended to inform resource allocation in maize research. This approach was linked to the growing capacity within CGIAR's farming systems research, with its focus on smallholder producers

(Collinson 2000). Following on this work, IFPRI's Spatial Analysis Group, formed in 2003, helped in characterizing the research context, differentiating recommendation domains for genetic and natural resource management technologies, and subsequently targeting delivery. Based on identification of similar agroecological zones and farmer systems spanning countries, researchers defined homogeneous production domains. These domains facilitate the development of regional frameworks used to organize research programs that can realize regional spillovers of technology and knowledge (as an example, see Johnson et al. 2011).

IFPRI continues this research today, with the use and improvement of data resources, such as the Spatial Production Allocation Model (SPAM); econometric approaches, such as stochastic frontiers analysis and data envelope analysis; and computational models, such as the Dynamic Research Evaluation for Management (DREAM) model, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), and the Rural Investment and Policy Analysis (RIAPA) model.[2] These tools are widely used to help policy analysts inform governments and funders about the contribution of agricultural R&D to productivity growth and poverty reduction, and to identify appropriate policy instruments to effect these changes. The tools are also central to the work of the Food and Agriculture Organization of the United Nations (FAO), many US land grant universities, and partners throughout the Global South. Notable examples include IFPRI's partnership with the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), which analyzed strategic priorities for agricultural development in eastern and central Africa by combining spatial data and analysis with a multimarket simulation model. The model was used to explore options to spur productivity growth, strengthen agricultural markets, and enhance links between economic sectors and countries (Lynam 2016; Omamo et al. 2006). This study provided an empirical and analytical foundation for relatively high-level priority-setting discussions within ASARECA, which then served as a model for the other subregional organizations and a basis for the World Bank's multi-donor trust fund that supports regional R&D frameworks, such as the East Africa Agricultural Productivity Program (Lynam 2016). These resources are, in short, a key asset of IFPRI's research portfolio.[3]

2 For more on these models, see www.ifpri.org/modeling-tools/

3 For more on this, see Alston et al. (2000), Fan et al. (2005), Nin-Pratt and Magalhaes (2018), and Pauw and Thurlow (2015).

This work on priority setting was augmented by IFPRI's Agricultural Science and Technology Indicators (ASTI) initiative, a long-term program that collected, analyzed, and shared internationally comparable time-series datasets on agricultural R&D investment and human research capacity in LMICs. Earlier research by IFPRI and partners focused on capacity, essentially in terms of staffing and budget allocation, particularly the primacy of recurrent staff costs over operational funds. Recent research by IFPRI and partners has expanded to link expenditure and staffing capacity to research outputs and outcomes, including agricultural productivity growth (for example, Nin-Pratt et al. 2023). Today, ASTI's work continues through the support of FAO, ensuring that the initiative's data continue to be collected, analyzed, and accessible over the long term, and numerous studies continue to use the ASTI dataset.[4] However, funding remains a problem, despite widespread use and recognition of ASTI's value.

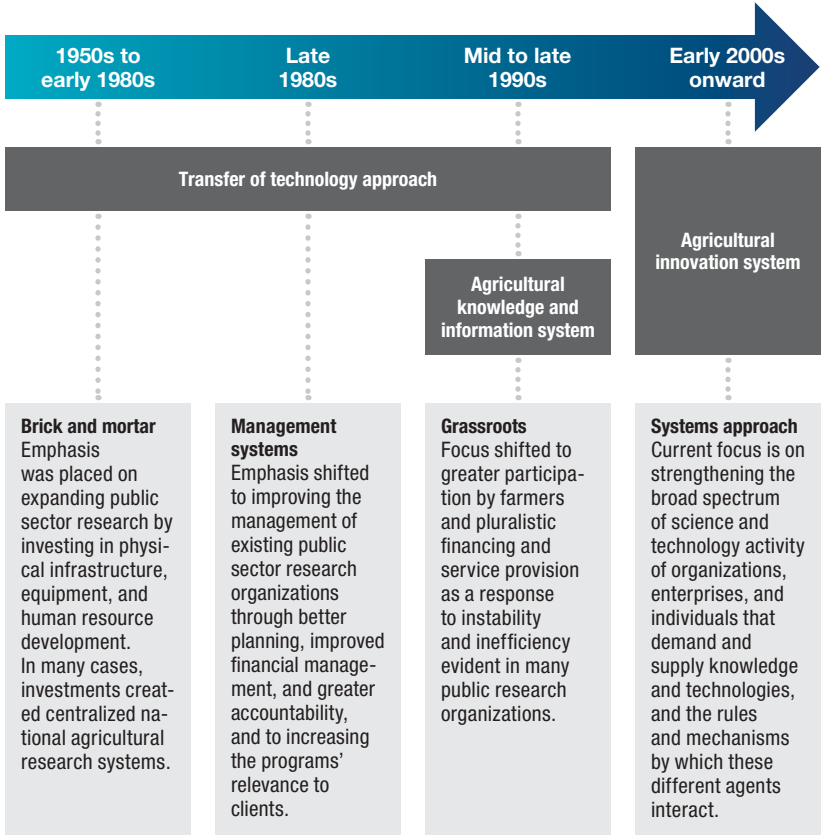
Systems thinking and broader development objectives

Policymakers often need innovative policy strategies and instruments to organize diverse actors around efforts to solve multiple problems. In agriculture, such problems include expanding the market and value chain for a particular crop or commodity or accelerating the widespread uptake of climate-resilient technologies and practices to bolster farmers against droughts, floods, heat, or other adverse weather events and improve their well-being. This task is difficult for policymakers to manage, especially for governments steeped in traditional top-down and centralized approaches to policy design and implementation.

At the center of this work is the recognition that technical change in agriculture is not simply a function of R&D investment. Rather, technical change is part of a broader process of innovation that occurs among a set of heterogeneous actors whose actions and interactions are shaped by social, economic, and political institutions, both formal and informal. This systems perspective continues to address the same productivity growth–poverty reduction challenge as the work of economists and other scientists described in the previous section, but expands to incorporate analysis of organizational and institutional challenges as well as policy options. Novel policy instruments include forming or funding various structures for coordination and

4 Examples include Alston and Pardey (2021), Carden et al. (2019), and Fuglie et al. (2022).

FIGURE 17.3 Innovation process within a changing context in LMICs



Source: Based on World Bank (2012).

inclusive processes; decentralization, devolution, or de-concentration policies; and reforms of public organizational structures or incentive systems. Policy research in this area includes documenting and assessing the effectiveness, sustainability, and impact of these structures on innovation processes and development outcomes to provide concrete recommendations on how to design, support, enable, and catalyze them.

Understanding of the innovation process has evolved substantially over the last seven decades in LMICs (Figure 17.3). Beginning in the 1950s, the operative model of agricultural innovation was the "transfer of technology" approach (Eicher 1984). In simple terms, this approach described a linear

process in which (1) universities trained researchers, (2) the researchers, based primarily, in national agricultural research systems developed technologies, and (3) extension services delivered technologies to farmers, resulting in productivity gains, food security improvements, and other desirable outcomes. The approach relied on scientific contributions from universities in industrialized countries. These contributions were adapted by international agricultural research organizations such as CGIAR, tested by national agricultural research systems in LMICs, and distributed to farmers by their extension agencies (see Chapter 8).

Introduction of the concept of agricultural knowledge and information systems (GFRAS 2012), which provided a more nuanced and nonlinear perspective on the subject, lent greater sophistication to understanding of the innovation process. Gaining popularity in the mid to late 1980s, this concept placed greater emphasis on the roles and coordination of research-extension-education actors and gave greater recognition to farmers' participation in the innovation process. The development of farmer participatory research and demand-led breeding shifted the focus from supply of technology to farmer demand and, in turn, to farmer innovation in adapting technologies within the farming system.

Until the 1970s, public investment largely focused on infrastructure and human resource development in national agricultural research organizations (Figure 17.3). Making meaningful changes to innovation processes, however, also requires some level of scientific, technical, and managerial capacity among national actors to ensure flows of human capital, information, and technology. Consequently, much of the policy research in the 1980s focused on understanding and improving the organizational capacity of public research organizations. Research also focused on the relative investment between R&D and extension and on improving institutional links between the two, especially with the World Bank's funding of training and visit extension. Partly because of the structural adjustment programs of the 1980s, which led to reductions in public spending on government services in the agriculture sectors of many LMICs, attention shifted to the exploration of organizational and institutional alternatives, including decentralization, privatization, contracting, outsourcing, and public–private partnerships (see Chapters 8 and 15). During this period of more than a decade, agricultural innovation was shunted to the margins of economic policy. Both public policy and budget resources were directed toward broader poverty reduction programs and shifted focus from agricultural development to rural development, which encompasses programming in health, education, and other social sector interventions.

It was not until the early 2000s that greater attention was paid to agricultural innovation, this time with a new conceptualization—the agricultural innovation system—inspired by research conducted primarily in the European industrial sector (Hall 2005; Klerkx et al. 2012; World Bank 2012). The agricultural innovation system concept has gained significant popularity, becoming mainstream in science, policy, and practice (Klerkx and Cremaschi 2025). Its central theme—the need to organize and coordinate across multiple actors and processes for greater market participation and social impact—has produced a multifaceted research agenda as well as practical methodologies to evaluate various institutional arrangements and partnerships. Examples include public–private partnerships, farmer collectives, innovation networks, multistakeholder platforms, innovation brokers, and clusters (Maryono et al. 2024; Spielman et al. 2012). These arrangements are designed to coordinate different agents within agricultural markets and reduce transaction costs in market participation. Multistakeholder processes and coordination structures are also developed around sustainability, agroecology, and nutrition (Maryono et al. 2024).

Multistakeholder innovation platforms have been mainstreamed in the largest sustainable intensification program in sub-Saharan Africa (Africa RISING), included in Uganda's national agricultural policy, and used in numerous agricultural projects. Similar approaches have been taken in South Asia through the Cereal Systems Initiative for South Asia (CSISA) and its predecessor, the Rice-Wheat Consortium. Popular market-oriented innovation platforms have been implemented in several programs in Latin America, such as the Papa Andina Project (Devaux et al. 2011). More recently, there has been stronger emphasis on sustainable development (nutrition, gender and social inclusion, climate resilience, agroecology, and sustainability), with stronger voices from social movements globally and with the emergence of new or renamed coordination structures, such as food systems innovation hubs, living labs for people, and transformation labs. Numerous studies show mixed results on the effectiveness, sustainability, and development impact of these approaches, owing to the wide diversity of their structure, degree of formality, objectives, size, and economic and social context.[5] Success stories include the positive large-scale impacts of China's Science and Technology Backyard (An et al. 2024; Zhang et al. 2016), and this empirical evidence can be drawn on to provide comparative and practical lessons on how to invest and support the sustainability and impact of these structures.

5 For example, see Davies et al. (2018), Maryono et al. (2024), and Schut et al. (2018).

IFPRI's work on this new approach dates to the mid-2000s, following its 2004 merger with the International Service for National Agricultural Research (ISNAR). Notable contributions include conceptual work on innovation systems (Spielman 2005), agricultural education and training (Davis et al. 2007), pluralistic extension systems (Birner et al. 2009; Davis et al. 2020; Spielman et al. 2021), private sector innovation (Naseem et al. 2010; Zhou and Babu 2015), organization of national research systems (Babu et al. 2015; Ragasa 2016), and measurement (Spielman and Birner 2008; Spielman and Kelemework 2009). Over the years, these contributions have been complemented by the work of many other organizations—Wageningen University & Research, FAO, the FAO–Agrinatura partnership on Capacity Development for Agricultural Innovation Systems, the Technical Centre for Agricultural and Rural Cooperation, the U.S Agency for International Development's Feed the Future Innovation Labs, the World Bank, the Institute of Development Studies, and other CGIAR Centers—and agriculture innovation systems now constitute a core theme of the CGIAR portfolio (Schut et al. 2024). Emerging assessments of the governance of diverse agricultural innovation systems highlight the need for continued and expanded research on this topic (for example, see Chen et al. 2024; Turner et al. 2020).

Scaling for impact

During the past 10 years, the innovation systems literature has rapidly evolved to address a fundamental question that continues to plague governments and their development partners: why have so many promising innovations failed to be adopted at scale, despite being successfully tested and piloted? These last-mile problems remain an enigma, as does the lack of novel policy options. Randomized, credible impact evaluations of interventions or innovations at small scale could play a critical role in informing scaling (Duflo 2004), yet few such evaluations exist for the agriculture sector. Among the available successful pilots from these randomized evaluations, there is limited evidence that they are scaled up or institutionalized at national or local levels.[6]

Effective scaling is often facilitated by a supportive policy environment that provides incentives for technology adoption and innovation. This bundling of policy change, technology options, delivery methodologies, market

6 This is explored by Abate et al. (2023), Gebreyes et al. (2021), Schut et al. (2020), Sinclair and Coe (2019), Spielman et al. (2021), and Stevenson et al. (2019).

links, and coordination mechanisms has become central to the scaling process, with interventions being piloted and scaled increasingly packaged as "socio-technical innovation bundles" (Barrett et al. 2022) or scaling-ready innovations (Schut et al. 2024). A critical consideration in scaling is the heterogeneity of actors and contexts. Planning within such heterogeneity has marked a return to geospatial analysis, complemented by "large data" and farm typology development (Hassall et al. 2023). Scaling strategies also need to strike a balance between globally scaled practices and local solutions, providing a middle path that avoids the inefficiencies of overly small-scale systems while steering away from the homogenization that global solutions often impose (Barrett et al. 2022). The economics or benefit–cost profiles of innovations often vary across scales (see List 2024), reinforcing the need for iterative impact evaluations at different scales. Further conceptualizations and frameworks on the role of economics in scaling are emerging, and applications in various sectors and programs are ongoing (al-Ubaydli et al. 2021; Halperin et al. 2022), but the economic concept for scaling science in agriculture has not caught up. For several decades, numerous donor agencies and international nongovernmental organizations set up structures and communities of practice and also documented lessons on scaling up development programs. Many scaling frameworks have been proposed (for example, Lam et al. 2020). Emphasis on scaling has become omnipresent within the development community, although many organizations and programs still largely focus on the reach and adoption of technologies and not on sustainability, strengthening of local institutions, or the systems change required for achieving impacts at scale (Woltering et al. 2019). Socio-technical innovation bundling has also been narrowly applied to bundling of inputs and services provided to potential beneficiaries (for example, Banerjee et al. 2024; Boucher et al. 2024; Mishra et al. 2023), rather than to finding solutions through policy, institutional, or systems change.

Within the agrifood system, CGIAR institutionalized the scaling approach with its Scaling for Impact Program. Between 2022 and 2024, CGIAR and partners co-created approximately 100 innovation packages, updated annually, organized in a global Performance and Results Management System, and made publicly available through the CGIAR Results Dashboard. The science of scaling work was initiated under the CGIAR Research Program on Roots, Tubers and Bananas, which published a special issue on the topic in the journal *Agricultural Systems* (Schut et al. 2020). Frameworks and management tools were made available to guide teams in examining their innovations and implementing their

scaling strategies (examples include Scaling Scan, Scaling Readiness, and GenderUp, among others; see compilation by Woltering et al. 2019). These tools offer rapid assessment of the scaling process and rely on expert opinion or a few key informants to provide ratings and scores of the different dimensions of scaling. Although they provide generic guidance on scaling pathways, these tools do not provide specific illustrations and guidance on what, where, how, or when to scale, nor do they inform on the ex ante and ex post impact evaluation of innovations, learnings on scaling successes and failures, or comparative cost-effectiveness of alternative scaling approaches. These are major gaps in knowledge and measurement in the scaling science literature. Documentations of lessons, barriers, and accelerators in scaling agricultural innovations are emerging (Barrett 2023; Herrero et al. 2021; Thornton et al. 2024), and these need to be expanded and compared to provide practical guidance for practitioners and decision-makers.

At IFPRI, researchers have contributed to the thinking on scaling pathways and documentation of lessons. In 2011, IFPRI's 2020 Vision Initiative produced a set of policy briefs that contributed to a better understanding of scaling up in agriculture, rural development, and nutrition around the world. These briefs delineate different pathways for scaling up initiatives, identify the key drivers that advance the scaling-up process and the key spaces that enable scaling up, and outline lessons learned (Linn 2012). IFPRI subsequently produced various assessments of agricultural technologies with potential for scaling (for example, Rosegrant et al. 2014); documented lessons on scaling up nutrition programs (for example, Gillespie et al. 2015) (see Chapter 12); illustrated methods to estimate heterogenous marginal effects of technologies and extrapolate effects from plot to national scale to inform scaling strategies or target beneficiaries (for example, Bedi et al. 2022; Komarek et al. 2019); documented lessons for scaling up group-based experimental games as institutional innovations in natural resource management (Meinzen-Dick et al. 2024) (see Chapters 5 and 6); and enhanced capacity and policy dialogues for scaling up natural resource management (for example, the Consortium for Scaling-up Climate Smart Agriculture in South Asia) (see Chapter 5).

HarvestPlus, an IFPRI program with a long history of partnership with CIAT and other CGIAR Centers, emphasized scaling strategies to maximize the global impact of biofortified crops (Box 17.2). Complementary to the collaborative breeding efforts, scaling strategies were developed; studies on the socioeconomic considerations and on nutritional sciences, led by IFPRI researchers with global partners, were foundational to the successful scaling of biofortification in various countries. For other biological innovations, such

BOX 17.2 IFPRI's programs on biofortification and biosafety: Integrated approaches

Biofortification program

The term "biofortification" refers to a plant breeding strategy to increase the micronutrient density of staple food crops and reduce the burden of micronutrient deficiencies in low- and middle-income countries. Initiated in 2003 and housed by IFPRI, the HarvestPlus biofortification program has invested approximately US$500 million in developing, testing, and scaling up biofortified varieties of 12 staple food crops (Bouis et al. 2024). Over 20 years, this relatively modest investment has enriched the diets of millions of people. At a high level of adoption, the benefits of biofortification accrue at little marginal cost, rendering it a highly cost-effective intervention to scale (Lividini et al. 2018).

The rapid scaling of biofortification has been facilitated by a body of evidence proving the efficacy and effectiveness of biofortified crops in improving micronutrient status and health, a rigorous monitoring approach, and a scaling strategy that introduces newly released crops into sustainable and commercial seed, grain, and food systems for broad consumption. HarvestPlus organized its activities under a coordinated, interdisciplinary program spanning advanced genetics, plant breeding, food processing, human nutrition, policy, and more. It works with decision-makers to embed biofortification in national, regional, and multilateral policies and programs; set global standards and targets for seed and grain nutrient concentrations; enable actors along the value chain and promote commercialization to stimulate public and private sector procurement and trade; and develop context-specific partnership approaches for fast diffusion and sustained adoption.

Biosafety program

Biotechnology adoption in developing economies initially progressed slowly in the 1990s due to trade, regulatory, and policy challenges. A significant shift began in 2003 when Brazil joined Argentina as leaders in adoption of genetically modified (GM) crops, with these two countries now accounting for 40 percent of the global GM-planted area. Latin America's GM adoption remains uneven, up from 6 countries in 2003 to 10 today, while Southeast Asia has 9 adopters out of 32 economies. In sub-Saharan Africa, only 6 of 48 economies plant GM crops, but notable progress in the last five years suggests a promising shift.

The policy landscape has evolved quickly, catalyzed by the advent of next-generation biotechnology tools, such as genome editing, that offer the promise of enhanced breeding speed and efficiency. The evolving policy

and technology adoption landscape in some African and Asian countries may be traced to several contributing factors, including capacity-strengthening activities offered by different entities and programs, such as IFPRI's Program for Biosafety Systems. These organizations have provided policymakers and stakeholders with sustained technical assistance, advising on rigorous science-based evaluation and approval processes to protect human health and the environment, and capacity-building projects, including tailored, locally led economic research and ex ante and ex post impact assessment of biotech innovations (such as Dzanku et al. 2018; Gouse et al. 2016; Ruhinduka et al. 2020), as well as studies on the cost of regulations (such as Falck-Zepeda et al. 2012; Falck-Zepeda and Gouse 2017), among others. The ultimate goal is to expand the number of safe and available biotech products that meet farmers' needs, making it essential to expand research on biotech innovations, with a particular focus on integrative and coordinated policy, governance, and scaling strategies.

Source: Inputs provided by IFPRI staff members Judy Chambers, Jose Falck-Zepeda, Patricia Zambrano, Jen Foley, and Rewa Misra.

as genetically modified organisms, IFPRI's Program for Biosafety Systems has contributed to the enabling technology and regulatory policy landscapes through sustained country-level technical assistance support, intensive capacity building, and an integrated approach to policy development (combining work on technical, intellectual property, legal, political, and communication issues), supported by a whole-of-government strategy that empowers local leaders and voices across the entire product development cycle. Greater impact of both innovations will directly depend on the further evolution of an enabling policy climate that recognizes and respects local context; generation of credible and broad-based social, political, technical, behavioral, and economic evidence; and communication of this evidence widely and effectively.

Outcomes

IFPRI's contribution to the economics of agricultural R&D has played an important role in sustaining public investment from LMIC governments and from their multilateral, bilateral, and philanthropic development partners and funders (Lynam 2016). Many of the models and tools developed by IFPRI are used today to guide research prioritization and resource allocation to achieve greater efficiency and impact in scaling of R&D investments.

IFPRI's work has also helped to create greater appreciation for the complexity of innovation systems and processes, which challenges the short-term, results-based program management that tends to eclipse other approaches in the development community. There are also signs of renewed emphasis on capacity development and sharing, at both individual and institutional levels, as seen in CGIAR's Capacity Sharing Accelerator program and other initiatives. This trend also demonstrates fundamental changes in strategy at the World Bank, FAO, and CGIAR.[7]

Over the past decade, IFPRI's work has helped advance organizational innovation in the agricultural space. Examples include the introduction of formal entities to better connect actors in research, extension, farming, and industry, including research-extension-farmer-industry linkage systems (REFILS) or district agricultural extension services system (DAESS); more permissive regulatory regimes that encourage public research engagement with the private sector, such as India's National Agricultural Innovation Policy and innovation platforms in Uganda's National Agricultural Policy; and innovative partnerships among actors around a particular innovation opportunity (see examples in Spielman et al. 2012).

Momentum appears to be building around the "decolonization of research" in the agricultural innovation space—that is, a shift in research leadership toward the Global South—and in the rise of national and regional organizations in the Global South, such as AGRA, Akademiya2063, ANAPRI, and a range of policy think tanks and networks in South Asia. The expanding role of IFPRI's regional and country offices is also part of this shift. A parallel shift is underway in the biological sciences—the introduction of participatory plant breeding and participatory varietal selection, which has advanced into citizen science and crowdsourcing approaches that draw on information and communication technology as well as big data to collect and analyze huge amounts of data from farmers. These data-driven, participatory, and transdisciplinary approaches are enabling the testing and evaluation of new varieties to reach more diverse farmers and farming systems faster and make it less costly to accelerate the large-scale adoption of these varieties (Occelli et al. 2024; van Etten et al. 2023).

Still, many scholars and experts have advocated for even greater investment in development of organizational and systemwide capabilities for agricultural innovation (see Hall 2005; Jayne et al. 2023; Klerkx et al. 2012). They have emphasized that although the scientific and technical capacities of individuals in national research organizations have improved over time, organizational

7 For more on this, see World Bank (2012), FAO (2022), TAP (2016), and Schut et al. (2024).

capacities in governance and management have not kept pace (Jayne et al. 2023). The following topics have been highlighted for greater learning and investment: designing and managing transdisciplinary research teams (Forsythe et al. 2024), building sustainable multistakeholder platforms and networks for agricultural innovation (Brouwer et al. 2019), integrating better and more systematic market intelligence into breeding, research, and scaling strategies (Donovan et al. 2022; Rice et al. 2024), and developing and sharing capacity more effectively (see CGIAR Program on Capacity Sharing).

Future research agendas

Our review points to three future research agendas. The first reflects the significant expansion in development objectives for which agricultural research investments are now held accountable (see Chapter 3). More work is needed to evaluate and model this wider set of development outcomes that address the complex realities facing governments today: how to maintain or increase the pace of economic growth and poverty reduction while also addressing the trade-offs associated with climate change adaptation and mitigation, environmental sustainability, the root causes of poor nutrition and health outcomes, and the problems of social inequality, exclusion, and marginalization. New methods and integrated frameworks will be required to better assess multiple policy objectives and better inform resource allocation and prioritization in the context of competing development goals. Driving investment decisions and informing resource allocation will require the systematic integration of spatial analysis, farm models, simulation, sectoral or economywide models using household data, and new approaches to measuring the research cost of innovations into a new framework. More spatially relevant (subnational, local) micro-level data on adoption and productivity impacts of relevant technology innovations and practices are much needed, as they are crucial parameters in macro–micro simulation modeling scenarios that inform the prioritization of resource allocation and assess impacts. Data and analysis on the costs of regulatory and institutional barriers and solutions would also be useful to integrate into investment planning and impact modeling.

The second research agenda focuses on best-fit approaches to scale solutions for agronomy and natural resource management. Although genetic innovations through improved varieties are much easier and more straightforward to deliver and scale widely (primarily through market mechanisms), innovations in systems agronomy or natural resource management in particular are inherently complex, nonlinear, and involve a mix of public and

private institutions (see Chapters 5 and 8). Scaling strategies will need to take this reality into account. What may look to the scientist like a context-specific application of well-established principles may represent a difficult set of choices for the farmer. Both genetic innovation and seed choices will need to be evaluated along with agronomic options, within the economic, social, and cultural context of the farmer. Strategic alliances between research organizations and development organizations could help build research on development projects that invest in enabling conditions for uptake of natural resource management practices. Such collaborations often occur in pilot programs, which are typically implemented in artificial contexts. Getting a more representative picture, therefore, will require moving toward collaboration in large-scale programs, especially those implemented by governments. Large-scale impact requires wide adoption of evidence-based innovations (guided by a transdisciplinary approach and iterative evaluations), which necessitates generating innovations suitable for a wide range of contexts and understanding which innovations are suitable for which contexts. A central research focus would explore how relevant institutions differentiate and target their programs and coordinate activities with other institutions.

The third research agenda involves rigorous impact evaluation of technological, social, and institutional innovations at different scales, and in-depth analysis of the political economy and enabling environment that drive or support agricultural innovations and scale their impacts. Many institutional innovations (organization and management practices, incentive systems, formal structures, and platforms) are being funded and piloted; rigorous evidence is needed on how they actually work and how they are sustained so that we can improve their design and make these structures more efficient and effective. Although substantial external support may lead to initial success, regular monitoring and assessment of these innovation platforms and hubs, as well as strategies for their sustainability, will need to be identified and put in place. For the numerous socio-technical bundles also being piloted, rigorous evidence is needed on how best to combine different interventions and elements of a bundle, and how to strike a balance between global or national best practices and locally relevant solutions. Iterative assessments, using participatory approaches as well as innovative and rigorous methods, need to be expanded to evaluate the cost-effectiveness and impacts of agricultural innovations and socio-technical innovation bundles across diverse contexts. Emerging assessments of the governance of agricultural innovation systems need to be expanded to improve understanding of the politics and power dynamics of innovation processes (see Chapter 15),

to address power imbalances and improve inclusion (see Chapter 14), and to identify innovative options for budgeting and financing the costs of institutional links and transactions (see Chapter 18). The "how" question will be a necessary focus of future research on agricultural innovation systems and the enabling environment for scaling impacts, with associated requirements for improved analytical methodologies.

Future policy research agendas will need to focus on assessing and designing new strategies for bringing innovative solutions to farmers' fields and achieving sustainable development impacts. Such agendas could include partnership-based scaling models and socio-technical bundles, proactive capacity development for national partners, and a data-driven approach to enhance the enabling environment for public policies and regulations that can facilitate these models and processes—all of which will require research based on transdisciplinary approaches and partnerships with national and local researchers. It is imperative that IFPRI researchers from various disciplines work closely with economists, nutritionists, natural biophysical scientists, sociologists, environmental experts, and legal and political scientists from other organizations to bring to the forefront the best solutions for the many complex challenges facing the world.

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